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ECLOGITE FROM THE CALIFORNIA GLAUCOPHANE SCHISTS.*

GEORGE SWITZER.

ABSTRACT. One of the varied rock types making up the California glaucophane schists is true eclogite, corresponding to typical eclogite in mineral composition, chemical composition, texture, and specific gravity. The California glaucophane schists, and therefore the eclogite, were formed under conditions of moderate temperature and pressure, by hydrothermal contact metamorphism The California eclogite is thus a mode of occurrence of this rock of a different type from those previously recognized by most writers.

INTRODUCTION.

IT was first suggested by Ransome (1894) that the glaucophane schists of the California Coast Ranges were formed along the periphery of intrusive serpentine bodies, from rocks of the Franciscan formation, by contact metamorphism. Several papers by other investigators give evidence to support the theory of a contact metamorphic origin for these unusual rocks. The most recent paper on this subject is that of Taliaferro (1942), in which is given a detailed account of the occurrence and mode of formation of the glaucophane schists. There now seems little doubt that contact metamorphism brought about by serpentine intrusives is the most reasonable explanation for the origin of these rocks.

The term glaucophane schist is broadly used to include a wide variety of rock types, some of which contain no glaucophane. All of these are intimately associated in the field and undoubtedly were formed nearly contemporaneously and through the same genetic process.

Holway (1904) designated as eclogite one of the rock types

* Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 265.

found in the California glaucophane schists. His determination was based upon one chemical analysis of a rock composed essentially of garnet and green pyroxene. No chemical analyses were made of the mineral components of the rock. Because of the contact metamorphic origin of the glaucophane schists, Holway's usage of the term eclogite has been questioned by some later investigators. For example, Taliaferro states (1942, page 1590):

> "Holway compared them with Scandinavian eclogite and stated that they were derived from intrusive gabbros. The green pyroxene (diopside) was called omphacite and the actinolite smaragdite. The eclogites of Norway and the Alps are the result of plutonic metamorphism and are everywhere associated with granulites, gneisses, and other completely metamorphosed rocks. The great difference in the mode of occurrence and association of the true eclogite and the Franciscan schists was not commented on by Holway. . . ."

It is true that in recent years the term eclogite has become almost synonymous with highest pressure and temperature conditions of metamorphism. In the facies classification of Eskola, eclogite is placed in the highest pressure-temperature group of all the metamorphic rocks. In the classification of Grubenmann-Niggli, eclogite is considered to belong to the katazone, or extreme depth zone of metamorphism.

However, it seems to the writer that the fact has sometimes been overlooked that eclogite refers to a rock composed of garnet and pyroxene having certain specified ranges in composition, irrespective of mode of origin.

During a study of the California glaucophane schists the writer found several occurrences of a rock corresponding to Holway's eclogite. A detailed study of these rocks showed them to be true eclogites in every respect. In this paper the word eclogite is used to denote a rock that consists essentially of (a) the pyroxene, omphacite and (b) a garnet in which almandite and pyrope are dominant. This is in agreement with Haüy's original definition.

FIELD RELATIONS.

The most notable occurrence of eclogite found is one mile east of the Junction School, on the Mill Creek road, near

Healdsburg, Sonoma County. Here is an area several square miles in extent covered with scattered outcrops of glaucophane schists of many types. The eclogite is restricted to a single outcrop approximately 50 x 50 feet. The whole schist area is long and narrow, extends in a northwest-southeast direction, and is bordered on the south by a serpentine sill striking approximately N. 50° W. and dipping 70° NE.

A second noteworthy occurrence of eclogite examined by the writer is near Reed's Station, Tiburon Peninsula, Marin County. This occurrence is restricted to a few small outcrops scattered over an area approximately 100 x 100 feet. Surrounding the eclogite outcrops is a larger area of various types of glaucophane schists. The glaucophane schist area is in turn in contact with a serpentine sill, which, standing nearly vertically, makes up the backbone of the peninsula.

Other smaller occurrences of eclogite were found at Jenner, on the south side of the mouth of the Russian River, Sonoma County; two miles east of Occidental, Sonoma County; and on the Syke Ranch, on the south fork of the Eel River, 10 miles northeast of Laytonville, Mendicino County.

PETROGRAPHY.

The California eclogite is megascopically deep green in color, more or less uniformly dotted with red garnets. Microscopically it is granoblastic, the grain size ranging from 0.05 to 2.0 millimeters. Garnet and omphacite are the most conspicuous minerals. Glaucophane, sphene, rutile, chlorite, and hornblende are present in small amounts.

The mode of an average specimen is approximately as follows: garnet 28 per cent, omphacite 57, glaucophane 2, hornblende 3, chlorite 4, sphene 4, rutile 2.

The average specific gravity of eclogite from several localities in Sonoma and Marin counties is 3.43.

MINERALOGY.

Omphacite: The pyroxene from eclogite found near Healdsburg, Sonoma County, California, was separated to a purity of 99 per cent and analyzed by Mr. F. A. Gonyer. The result

TABLE I.

Pyroxene from California Eclogite.

	1.	2	3.	4.	5.	6.
SiO_2	53.31	0 888	1.776	0.888	1.94	1.95
TiO_2	0.26	0 003	0.006	0.003	0.01	
Al_2O_3	10 52	0.103	0.309	0.206	0.45	
Fe_2O_3	4.11	0.026	0.078	0.052	0.11	
FeO	2.84	0.040	0.040	0.040	0.09	1.10
MnO	0.05	0 001	0.001	0.001	..	
MgO	8.42	0.208	0.208	0.208	0.45	
CaO	14 50	0 258	0 258	0 258	0.56	0.97
Na_2O	5.90	0.095	0 095	0.190	0.41	
K_2O	0 05	0.001	0.001	0 002	. .	
$H_2O(+)$	0.16	0 009	0.009	0 018	0 04	
	100 12		2 781	f=2 16		

1 *Omphacite*—from eclogite near the Junction School, Mill Creek area, Healdsburg Quadrangle, California. F. A. Gonyer, analyst Analysis first published by Birch (1943).

2. *Molecular ratio.*

3. Oxygen atoms of ratio given in column 2.

4. Positive atoms of the ratio in column 2.

5. Ratios of column 4 each multiplied by the factor f, in order to bring the total oxygens to 6.

6. Isomorphous groups of atoms combined to yield the formula (Ca,Na) (Mg, Fe″, Fe‴, Al) Si_2O_6.

of the analysis is given in Table I. The one per cent impurity was chiefly sphene.

In Table II the California pyroxene is compared with pyroxene from three other localities. It is apparent from this comparison that the California pyroxene is a typical eclogite pyroxene, the soda-rich variety commonly called omphacite.

Garnet: The garnets of the glaucophane schists of California have been described in detail by Pabst (1931) who found that there is considerable range in their composition. The proportion of almandite is especially constant, varying from 48 to 56 per cent. The grossularite content varies from 8 to 21 per cent, andradite from 4 to 24 per cent, and pyrope from 10 to 20 per cent. The California eclogite garnets fall within the composition ranges defined by Eskola (1921) and Heritsch (1926) as being characteristic of eclogite garnets.

Associated minerals: In addition to omphacite and garnet

TABLE II.

Composition of Pyroxene from Eclogites.
Metal Atoms on Basis of Total Oxygen Number of 6.

	1.		2		3.		4.	
Si	1.94	1.95	1 97	2.00	1.98	1.99	1.93	1 93
Ti	0 01		0.03		0.01		–	
Al	0.45	1.10	0.42	1.03	0.44	1 05	0 30	1.02
Fe'''	0 11		0 08		0.16		0 08	
Fe''	0 09		0 18		0.10		0 04	
Mg	0 45		0.35		0.35		0 60	
Ca	0 56	0.97	0.59	0.90	0.50	0.88	0 64	0.94
Na	0.41		0.29		0 37		0 27	
K	–		0.02		0 01		0 03	
O	6		6		6		6	
α	1 673*							
β	1.679		1.70		1.67		1.683±0.002	
σ	1 691							
Sign	(+)				(+)			
2V	60°				2E=140°		67°	
	Y=*b*							
Orientation	Z·*c*=39°		Z:*c*=43°		Z:*c*=36°		Z:*c*=42°	
Sp. Gr.	3 34±0 02		3 31		3 31		3.30	

* Indices in column 1±0 002.

1. *Omphacite*—near the Junction School, Mill Creek Area, Healdsburg Quadrangle, California. F. A. Gonyer, analyst. Analysis first published by Birch (1943).

2. *Omphacite*—from hills west of "Postman's Path," Ardintoul Glenelg, Inverness-shire, Scotland. A. R. Alderman, analyst (Alderman, 1936).

3. *Omphacite*—Fay, France. Raoult, analyst (Brière, 1920).

4. *Omphacite*—Silden, Norway. P. Eskola, analyst (Eskola, 1921).

several other minerals are found in varying amounts in the eclogite. These other minerals are not of contemporaneous origin with omphacite and garnet, but were formed at a later stage in the genetic history of the rock. The eclogite constituents, in the approximate order in which they were formed, are as follows: garnet and omphacite, hornblende, muscovite, clinozoisite, actinolite, glaucophane, pumpellyite, lawsonite, albite, quartz, rutile, sphene, chlorite, and pyrite.

Omphacite and garnet were formed together, the garnet having formed as euhedral crystals in a granular pyroxene groundmass. There is a small amount of muscovite present which is commonly concentrated about the garnet crystals.

A second set of minerals is clearly later than the main eclogite. The most abundant of these are hornblende, glaucophane, rutile, sphene, chlorite, and pyrite. The occurrence of these minerals is almost entirely restricted to narrow seams or fractures irregularly traversing the massive eclogite. The hornblende is usually concentrated along narrow fractures. Occasionally hornblende has entirely replaced the omphacite with a resultant rock that is a typical garnet-amphibolite. Glaucophane is, in the same way, strikingly concentrated along fracture planes in the main eclogite mass. It is often found as peripheral zones about hornblende. Chlorite is also strongly concentrated along narrow fractures, with sphene, glaucophane, hornblende, and pyrite. In thin section chlorite can be seen replacing garnet, hornblende, and glaucophane. The sphene has formed in white to pale-yellow anhedrons up to one centimeter in size, associated with smaller amounts of rutile. Pyrite is common and is also restricted in its occurrence to the seams of late formed minerals.

DERIVATION.

One chemical analysis has been made of California eclogite (Holway, 1904). Another has been calculated by the writer using the mode given on page 3, and chemical compositions of the constituent minerals is given in Table I and by Pabst (1931). These analyses are given in Table III, with three eclogite analyses from other localities, and one analysis of Franciscan basalt. The California eclogite corresponds well to those of Norway, Switzerland, and Scotland, and to the basalt.

Field relations show clearly that the California eclogite is one of the varied rock types making up the California glaucophane schists. In addition, the eclogite is closely associated with Franciscan basalts and was undoubtedly derived from them by hydrothermal contact metamorphism caused by serpentine intrusives.

There is no evidence to indicate that the Franciscan horizon now exposed at the surface was at any time deeply buried. It seems certain, therefore, that the eclogite was formed under conditions of moderate pressure. Low temperature of the peridotite magma at the time of its intrusion is indicated by complete lack of thermal metamorphism along the contacts where no glaucophane schist is found.

TABLE III.

Eclogite and Basalt Analyses.

	1.	2.	3.	4.	5	6.
SiO_2	44.15	46.5	50.21	41.5	44 06	46.60
TiO_2	trace	3.6	1.69	1 2	2.29	2 87
Al_2O_3	10.18	13.5	13.78	15.9	17.63	15.28
Fe_2O_3	11.92	3.8	1 49	3.4	3 40	3 98
FeO	13 04	8 0	11 32	16.2	9 96	8.17
MnO			0 18	0.4	n d.	0.08
MgO	16 18	7.5	6.69	4 2	7.19	5.4
CaO	4 51	13 5	11 09	12.4	11.58	10 68
Na_2O	5.11	3 6	2.12	2.6	2.92	2.26
K_2O	2 09		0.44	0.1	0.91	0.85
H_2O (+)	0.95		0.24	0.2	0.17	3 63
H_2O (−)			0.13		0 12	0 24
P_2O_5			trace	2.4		0 36
F			n.d.	0.2		
Cl			0.07			
SO_3			0 13			0.08
CO_2			0.05			0.06
	99.31	100.0	99.56	100.7	100.23	100.28
Sp.Gr		3.442		3.61	3 54	2 85

1. *Eclogite*—Coyote Creek, six miles northeast of San Martin, Santa Clara County, California. Composed of garnet 40 per cent, omphacite 40 per cent, actinolite, glaucophane, and white mica together 20 per cent. C. B. Allen, analyst (Holway, 1904).

2. *Eclogite*—near the Junction School, Mill Creek area, Healdsburg Quadrangle, California. Composition calculated from analyzed mineral constituents and mode. (Specific gravity measured by F. Birch.)

3. *Eclogite*—hills west of the "Postman's Path" to Ardintou, Glenelg. H. R. Alderman, analyst (Alderman, 1936).

4. *Eclogite*—Duen type, Vanelosdalen, Sondmore, Norway. Analysis calculated from mode of analyzed minerals (Eskola, 1921).

5. *Eclogite*—Sulztal, Ötztal, Tyrol (Hezner, 1903, p. 446).

6. *Basalt*—near the mouth of Duvuol Creek, two miles north of Camp Meeker, Sonoma County, California. F. A. Gonyer, analyst.

CONCLUSION.

The known occurrences of eclogite have recently been summarized and classified into the following six types (Davidson, 1943):

(1) Schlieren and lenses in garnet-bearing anorthosite.
(2) Schlieren and lenses in garnetiferous charnockite, pyroxene-granulite or pyroxene-gneiss.
(3) Lenticular masses in granite-gneisses and migmatites.
(4) Schlieren and segregations in peridotite and dunite.

(5) Sheet-like masses, associated with amphibolite, in paragneiss.

(6) Nodulcs, associated with peridotite and other ultrabasic tyes, in kimberlite pipes of South Africa.

To these well-recognized types of occurrence should be added the California type:

(7) Irregular masses, associated with glaucophane-bearing rocks, formed by hydrothermal contact metmorphism under moderate temperature and pressure conditions. Intrusive peridotite sills and dikes were the metamorphosing agents.

ACKNOWLEDGMENTS.

This paper represents a portion of a general study of the glaucophane schists of California that was made possible by financial aid from two sources, the Holden Fund of the Department of Mineralogy, Harvard University, and Mr. M. Vonsen, of Petaluma, California. For this assistance the writer is deeply grateful. Professors Charles Palache and Esper S. Larsen, of Harvard University, have been most generous with aid of many sorts.

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GLACIAL BORDER DRAINAGE AND LOBE-EDGE EMBANKMENTS.

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ABSTRACT. An active continental ice-sheet pushing against a hillside may construct a morainic embankment along its margin. The presence of such an embankment is thus positive evidence of active glaciation, as opposed to stagnation. For it, the term "lobe-edge embankment" is proposed. Since the ice may at the same time be causing stream diversion, the embankment may be associated with temporary drainage channels. The presence of such channels by themselves, however, is not indicative of either active or stagnant retreat.

IN the course of field work[1] carried on in Western Massachusetts at intervals over the past six years, the writer has observed repeatedly a type of feature which, in his opinion, warrants considerably more attention than it has received in the past.

DESCRIPTION OF THE FEATURE.

In its most recognizable form, this feature appears as a long, narrow ridge, with an undulating crest, 2 to 30 feet in height, running along a moderately steep mountainside in a direction parallel to the general trend of the contours. Wherever cut by a brook ravine or a roadway, this ridge will be seen to be composed of a heterogeneous mass of unassorted material, ranging from clay to large, subangular, often striated stones. Between it and the rising hillside lies a long, narrow swale. At first glance, the bottom of the swale will appear to be essentially horizontal longitudinally, but a levelling of it will usually indicate a gentle decline in one direction,—usually toward the south or east.

Frequently these ridges occur in groups, one above another on the same hillside. In other places, the ridge crest, followed along the hillside, will be seen to fall to the level of the swale, and the whole ridge-swale combination gives way to a narrow bench banked against the hillside. Followed to its lower end, the feature usually terminates in a flat gravelly plain, or in an area of conical gravel hills.

Several excellent examples of these features may be found

[1] Part of the field work on which this article is based was carried on through a grant from the William Libbey Fund for Research in Physical Geography, under the auspices of Clark University.

in Western Massachusetts. One, on the road from Hartsville to New Marlboro, about one mile south of the former place, is cut by the highway and a small brook, offering a good cross-section. Another occurs a few hundred yards west of State Route 8, 4 miles south of Hinsdale, Massachusetts, and just north of the dirt road known locally as the "Beech Road".

POSSIBLE EXPLANATIONS.

1. *Hogback.* Except for its internal constitution, the description given above might be applied to a hogback—a ridge owing its existence to the superior resistance of an inclined stratum. Hogbacks do occur at places within the area, but are easily distinguished by the frequent outcropping of bedrock on their top and sides.

2. *Esker.* An esker is a long, narrow ridge with an undulating crestline, formed by deposition in the bed of a glacial stream, held in by walls of ice. Outwardly, the features described above resemble eskers, but the material of which they are composed prevents them from being classed as such. Eskers are composed of gravelly material, roughly assorted and containing a large proportion of well-rounded pebbles.

3. *Landslide Material.* Only two agencies are likely to create a mass of material whose composition is as heterogeneous as that forming the ridges in question: landslides and glaciers. Considering the material alone, these ridges might be attributed to landslide deposition, but topographically they are completely unlike anything that might conceivably result from such phenomena. While landslide deposits do have a "swell and swale" topography at times, there is always a lack of continuity to such features, and certainly never the perfection of slopes as is exhibited in these swales.

4. *Crevasse Fillings.* Ridges similar in outward appearance to an esker, but composed of material ranging from roughly assorted to completely unassorted, have sometimes been explained as the result of material being avalanched into and partly filling crevasses in an ice-sheet. Such an explanation might seem to apply here, but a more careful consideration will reveal that it explains only one-half of the feature—the ridge; for the swale, especially in its continuity and its longitudinal slope, it offers no explanation.

5. *Border Drainage and Morainic Embankments.* It is conceivable that in the glaciation of a mountainous country by a

continental ice-sheet, the situation would frequently occur in which the edge of a lobe or tongue of ice occupying a valley would lie close against the neighboring mountainside. The forward motion of the ice would continually carry debris to the front, and it would be deposited there, against the mountainside. Meltwater, issuing from the ice-sheet would have to find its way along the sag between the ice-front and rising slope of the mountain. Where this flow was weak, it would have little effect on the deposition of debris, but where the volume of meltwater was great, it would of necessity maintain a channel for itself, carrying away material as it was dumped from the ice. Deposition would still go on beneath the edge of the ice, however, and protected by the ice, would build up a considerable pile of detritus.

At some places where the ice stood at a greater than average distance from the mountainside, or where the line of its contact descended to an elevation lower than at other adjacent points, a "pocket" would be formed which would promptly fill with meltwater. In this temporary, ice-bound lake, the meltwater would deposit much of its load of detritus, and in time, the "pocket" would be filled with sand and gravel to the level of the lowest point in the rim.

The subsequent withdrawal of the ice-sheet would leave the

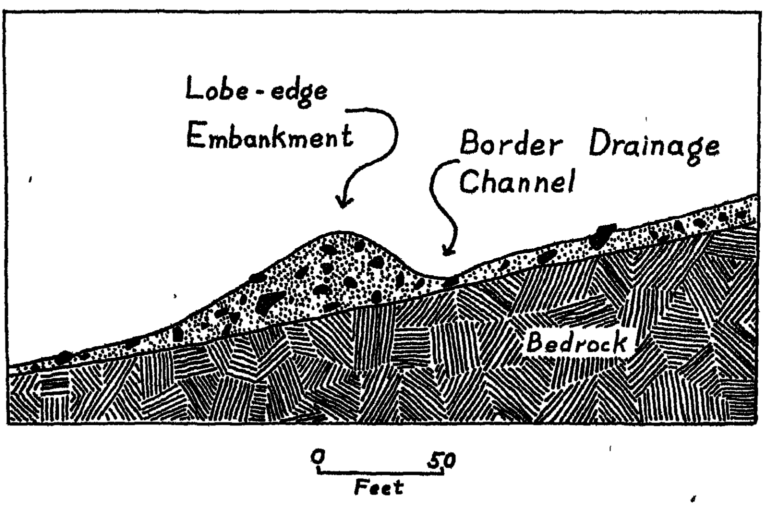

Fig 1 Generalized cross-section through a "lobe-edge embankment" and its associated border drainage feature. Vertical and horizontal scale the same.

pile of detritus dropped under the edge of the ice standing as a long, narrow ridge roughly paralleling the trend of the hillside, and bordered on its uphill side by the channel of the escaping meltwater. Where a temporary lake had existed, the swale-like character of the meltwater channel would broaden into a gravelly plain if the lake had been filled, or into a swampy tract if deposition had not been so great. There might be a disappearance of the ridge at such places, especially if the ice-front had dropped to a lower elevation, and the plain would stand as a terrace banked against the hillside.

A cross-section through the ridge (Fig. 1) will show it to be composed of an unassorted mass—till—dropped directly by the ice. A cross-section of the swale would be less uniform: some parts, where deposition occurred, will show stratified sands and gravels; other places, where erosion was dominant, it will show as a channel cut in till, with perhaps a surface concentration of larger stones—rock too large for the meltwater to transport, and hence left behind while the remainder of the till was removed. Much of the swale will have a surface coating of more recent materials: swamp materials, solifluction deposits, slope wash from the adjacent hillside, and small alluvial fans at the points where steep hillside rills have had their gradients reduced on entering the swale.

The presence of more than one ridge-swale combination on the hillside is due to a succession of halts and recessions. The oldest of the succession is, of course, the highest in elevation.

For the swale, resulting as it does from the flow of meltwater along the ice-edge, the term "border drainage channel" has long been used. No term having been assigned to the ridge, the writer suggests that the term "lobe-edge embankment" be applied to it.

PREVIOUS LITERATURE.

The possible existence of these ice-border features has not received much attention on either side of the Atlantic; the literature concerning them is scanty and widely scattered.

So far as the writer is aware, the first description of such features is contained in an article by Kendall[2] on the Cleveland Hills of Yorkshire, England. He shows that during the deglaciation of that hilly region, meltwater found its escape along

[2] Kendall, P. F: 1902, "A System of Glacier Lakes in the Cleveland Hills" Quart Journ. Geol. Soc vol. 58, p. 471.

the margin of the ice, in some places confined to a narrow stream channel, and elsewhere allowed to broaden into lakelike expanses. The swifter reaches of streams maintained channels in the till, and at some places eroded the underlying bedrock.

About the same time Taylor,[3] studying the glacial deposits of Berkshire County, Massachusetts, recognized similar features in that area. While Kendall, in the Yorkshire area, had recognized chiefly erosional action in the form of stream erosion —Taylor observed that deposition had, in the Berkshires, occurred at the same time. However, even he seems to have failed to appreciate the full significane of the ridge, putting too much emphasis on the erosive power of the stream. He states, "Where border drainage was very strong, a ridge of coarse detritus was sometimes built along the edge of the ice, and left there on its retreat as a distinct, narrow ridge forming the outer bank of the river bed."[4]

Lougee has described many such channels in two papers[5] dealing with New Hampshire. In each case he stresses the erosive action by the meltwater, but does not mention whether there is a ridge of till bounding the channel on one side. These till ridges are the most significant part of the whole feature; by their presence, an important controversial issue can be definitely settled in any given area.

SIGNIFICANCE OF LOBE-EDGE EMBANKMENTS.

Thus far it has been assumed that the ice-sheet was actively moving forward throughout the period of the formation of these border drainage features. However, at various times during the past half-century the hypothesis has been presented that in New England the ice-sheet stagnated at about the time of its maximum extent, and melted from the top down. It would be valuable if a means could be found by which the fact of either stagnation or active movement of ice in a given area could be determined beyond any doubt.

In some cases, these lobe-edge embankments appear to offer

[3] Taylor, F. B.: 1903, "Correlation and Reconstruction of Recessional Ice Borders in Berkshire County, Massachusetts", Journal of Geology, vol. 11.

[4] Taylor, op. cit. p. 337.

[5] Lougee, Richard J.: 1939, "Geology of the Connecticut Watershed", Biological Survey of the Connecticut Watershed, N. H. Fish and Game Dept. Survey Report No. 4, pp. 135; 140-144.

Lougee, Richard J.: 1940, "Deglaciation of New England", Journal of Geomorphology, Vol. III, pp. 207-218.

such a method. Let us first review the events immediately preceding, during and immediately subsequent to their formation under conditions of active ice movement, and then compare these with the conditions along the border of a stagnant lobe in a similar situation.

Under normal circumstances, the front of a receding ice-sheet melts back a fairly regular distance in any given period. Simultaneously, the ice-sheet itself is moving forward, so that new ice and new detritus is continually being brought to the front. The detritus is dropped by the melting ice and forms a thin covering of heterogeneous material over the bedrock, known as "ground moraine". Meltwater is discharged from the ice-front and flows along the trench between the ice-sheet and the mountainside; but since the ice-front is constantly receding, it has little time to construct regular channels.

Occasionally, however, the weather changes sufficiently to cause the rate of melting to decrease to the point where the rate of melting is equal to the rate of forward motion of the ice-sheet. Thus the ice-front remains stationary for a time. But all the time forward motion within the ice is going on, new detritus is being carried forward and deposited, and meltwater is coursing through the trench at the ice-front. It is during this period of stability that the hillside embankments will form. After a time, the weather again changing, the rate of melting will increase, and the ice-front will once more recede. Again only a thin coating of ground moraine will be deposited.

Thus, under conditions of normal, active ice retreat, the ordinary, thin ground moraine covering most of the hillside will give way to a ridge of thick till on the iceward border of the meltwater channel.

Stagnant ice has no forward movement, thus there will be no continuous supply of new detritus coming to its front. It will, however, have periods of stability of the ice-front, followed by periods of faster recession; thus during certain times, the meltwater channels will be continuously changing, and at other times, will remain fixed for a considerable period in one place. It is during the latter periods that border drainage channels may be established along the ice-front. Ground moraine deposited by stagnant ice will consist only of whatever material is held in the ice directly above the spot concerned. Hence a long halt of the ice front at a given point will not in any way increase the thickness of till there.

Thus the rule may be stated: IF THERE IS A CONSIDERABLE THICKENING OF THE GROUND MORAINE TO FORM A RIDGE ON THE OUTER (DOWNHILL) SIDE OF THE BORDER DRAINAGE CHANNEL, THE ICE WAS ACTIVELY MOVING AT THE TIME OF ITS FORMATION. It does not necessarily follow, however, that the absence of this thickening would be proof of the stagnant condition of the ice-sheet; for it is perfectly conceivable that the channel might be carved in till deposits along an active ice-front in a period too short for the accumulation of a thickened till mass. For example, it is possible that a suddenly increased volume of water flowing through the trench might carve the channel in comparatively few hours; and such quick surges of water were no doubt a common occurrence under glacial conditions in a mountainous region, caused by the sudden release of an ice-impounded lake.

Once it has been established that in a given area the ice possessed active motion during the period of its recession, it becomes of great importance to the field worker to determine the slope maintained by the ice-sheet in the zone immediately behind the ice-front. Since in most hilly regions, the sheet took on the form of a number of lobes protruding into each of the valleys of the area, the deposits of a given moment would be found through a wide range of elevation. With a knowledge of the slope of each lobe, correlations between frontal deposits can be made over considerable distances.

Because the border drainage runs in the trench at the contact of a lobe and the neighboring hillside, it offers a convenient means of determining the slope of any particular lobe. The unevenness of deposition causes a considerable undulation of the crest of the morainic ridge, but the smoothing effect of stream action makes the swale both a good indicator of the slope and a convenient place to run a line of levels. In determining the slope of the ice-edge by this method it should be borne in mind that the slope determined will be less than the slope along the axis of the lobe, since there is always a slope from the central portion of a lobe toward its peripheries, lateral as well as terminal.

CONCLUSIONS.

In a hilly region undergoing continental glaciation, meltwater escaping through the lower area between the ice-front and the

mountainside, may scour a channel in the underlying till and bedrock. This will be left, after the retreat of the ice, as a channel running along the hillside, sometimes bordered on the outer side by a ridge of till, sometimes standing as a gravelly terrace. If it is accompanied by a considerable thickening of the till on the downhill side, it is an indication that the ice was actively moving throughout the period of its deposition; but the lack of such thickening is not proof of stagnation. The slope of the channel may, under ideal circumstances, give a rough approximation of the slope of the ice-lobe by which it was formed, and may serve as a means of correlating detached morainic fragments.

ACKNOWLEDGEMENTS.

The writer wishes to express his appreciation to Dr. Wallace W. Atwood, Jr. of Clark University, for having made possible some of the field work on which the article is based; to Paul Martin and J. Ross Mackay, both formerly of Clark University, for assistance in the field; to Prof. Richard J. Lougee of Colby College, for having first called the writer's attention to the feature and the paucity of literature on the subject; and to Dr. Howard A. Meyerhoff of Smith College for his careful reading of the manuscript, and valuable suggestions concerning it.

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PROLACERTA AND THE PROTO-ROSAURIAN REPTILES.

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PART I.

ABSTRACT. A second specimen of *Prolacerta* from the Lower Triassic of South Africa is closely related to *Protorosaurus speneri*. Since *Prolacerta* must remain closely associated with the Permian "*Eosuchia*" it now becomes necessary to place *Protorosaurus* in that group. It may be preferable to retain the old name *Protorosauria* in place of "*Eosuchia*" *Prolacerta* shows characters intermediate between *Youngina* and the lizards, also characters intermediate between *Youngina* and the rhynchocephalians *Prolacerta* may be somewhat closer to the lizards as it seems to be incipiently streptostylic

INTRODUCTION.

DR. F. R. Parrington of Cambridge University has recently described, under the name *Prolacerta broomi*, the fragmentary skull of a small lizard-like reptile from the *Lystrosaurus* beds of South Africa. Parrington concludes that *Prolacerta* is "intermediate between a primitive group (the Eosuchia) and the lizards," and is the type of a new family, the Prolacertidae assigned by him to the Thecodontia.

When Parrington's (1935) paper appeared Mrs. Camp and I were traveling to South Africa under a fellowship generously provided by the John Simon Guggenheim Memorial Foundation. At Harrismith Mr. Leonard Putterill and his nephew Mr. Cowper Smith very kindly guided us to the famous localities, discovered by the late A. W. Putterill. There we were so fortunate as to find another skull of *Prolacerta*.

Preparation of this material was furnished by the personnel of the Works Progress Administration, Official Project No. 65-1-08-62, Unit A-1. Mr. Owen Poe has prepared the illustrations. The California Museum of Vertebrate Zoology has kindly loaned cleared specimens of recent lizards, prepared by Mr. Thomas L. Rodgers.

DESCRIPTION OF NEW MATERIAL.

Specimen.—Skull and six articulated cervical vertebrae and ribs, in hard grey limestone nodule, No. 37151, U. C. Mus. Pal., prepared by Martin Calkin, (Plate 1).

Locality.—One mile east of Harrismith, Orange Free State, Union of South Africa; *Lystrosaurus* zone, assigned to the Lower Triassic of the Karroo Series. Found in place in the steepest exposure at "Big Bank," below the Municipal dam. U. C. Mus. Pal. Loc. 36115.

Occurrence.—The elongate nodule containing the entire specimen lay in one of the light gray, silty limestone members of the *Lystrosaurus* zone. A small skull of *Lystrosaurus* was found in the same level at this locality. Dongas in the vicinity but at slightly different levels have produced dozens of skulls and skeletons of the common aquatic dicynodont, *Lystrosaurus*, also the aquatic amphibian *Lydekkerina*, the predacious aquatic thecodont *Chasmatosaurus*, and the small carnivorous cynodont reptile *Thrinaxodon*. *Thrinaxodon* does not appear to have been aquatic, though it may have had habits similar to those of a mink.

The adjacent sediments are red, calcareous clays with granular limestone nodules, gray shales and some lenses of bone breccia. It seems probable that the beds were laid down in shallow lakes or swamps.

The skull elements have been slightly dislocated in the matrix, evidently by uniform pressure sufficiently heavy to force the elements apart along suture lines without extensive deformation or breakage. The seven anterior cervical vertebrae are slightly separated from the atlas, and twisted over to the right. The elements of the atlas are dismembered and one is broken, possibly from the bite of some predator.

The last cervical vertebra preserved lay enclosed within the nodule and at some distance from the end of the nodule. So it is evident that the remainder of the carcass had become separated before burial of the head and neck.

Diagnosis.—Cervical vertebrae large, amphicoelous, with small notochordal pits. Intercentra now represented by the large concentric intercentra of the atlas and axis, and by a much smaller, slightly displaced intercentrum lying below the juncture of the third and fourth centra. No pronounced keels on the intercentra. Dichocephalous ribs on all cervical vertebrae. The lower end of the small, rod-shaped quadratojugal rested upon a shoulder on the external border of the quadrate. Jugal with a slender posterior process reaching nearly to the quadrate. Dorsal skull elements all paired along the mid-line. Nasals very large, snout narrow and pointed, external nares

small. Postfrontals primitive in shape and position, resembling those found in *Youngina* and early reptiles. Interparietal doubtfully present and, if so, vestigial. Pineal foramen very small or absent. Squamosal much as in *Sphenodon*; supratemporal absent, fused with squamosal, or very doubtfully represented by a small element at the tip of the parietal. Palate exceedingly dentulous, with numerous teeth on vomers, palatines and pterygoids. Pterygoids articulating with vomers. Basioccipital relatively small and narrow. Parasphenoid well ossified and with a long rostrum. Paroccipitals and exoccipitals separate. Epipterygoid with a quadrate process. Orbit large, with 12 or 13 sclerotic plates. Lower jaws slender throughout, unfenestrated, and with elongate posterior process. Dentition pleuro-thecodont, teeth hollow at base and fused to upper margins of alveoli when fully erupted. Tooth replacement successional. No osteoderms preserved; skull elements smooth, unsculptured.

Comparison with type.—The present specimen agrees in detail with the type skull described by Parrington (1935), so far as the two may be compared. Thus the shape of the parietal and the supratemporal fenestra, the shape of the frontal and postfrontal, and the relative positions of the quadrate, squamosal, quadratojugal and postorbital are so similar as to leave no doubt as to the generic identity of the two specimens.

When due allowance is made for the relative imperfection of the Cambridge skull some discrepancies may be accounted for. Accordingly, it seems probable that the lack of a posterior process on the jugal, the ventral position of the quadratojugal, the position of Parrington's "supratemporal," and the shape of the squamosal in the Cambridge specimen are due to faulty preservation—crushing, cracking, and loss of parts.

Description of skull.—The PREMAXILLARIES meet on a rough midline suture. The short nasal and maxillary prongs are of equal length, forming a crescent. The maxillary process enters an external notch on the tip of the maxillary. The nasal process lies between the tips of the nasals. The palatal process is largely concealed.

There were five teeth in each premaxillary, somewhat smaller than those in the maxillary. The shallow, cup-shaped alveoli are more open lingually than bucally, possibly an approach to pleurodonty, as the fully erupted teeth are fused to the edges of

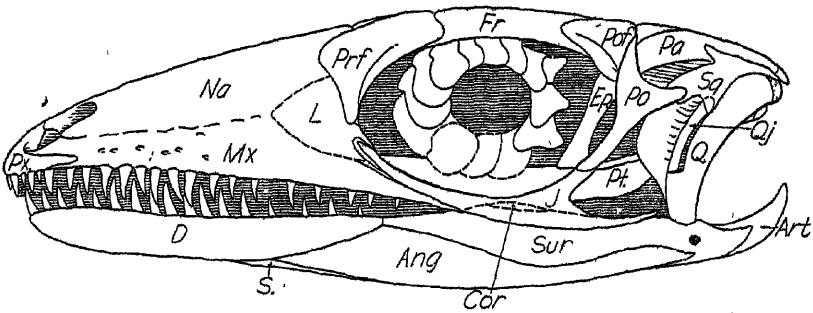


Fig. 1. Lateral view of skull of *Prolacerta broomi*, U C Mus. Pal. no. 37151, x 2. Reconstructed.

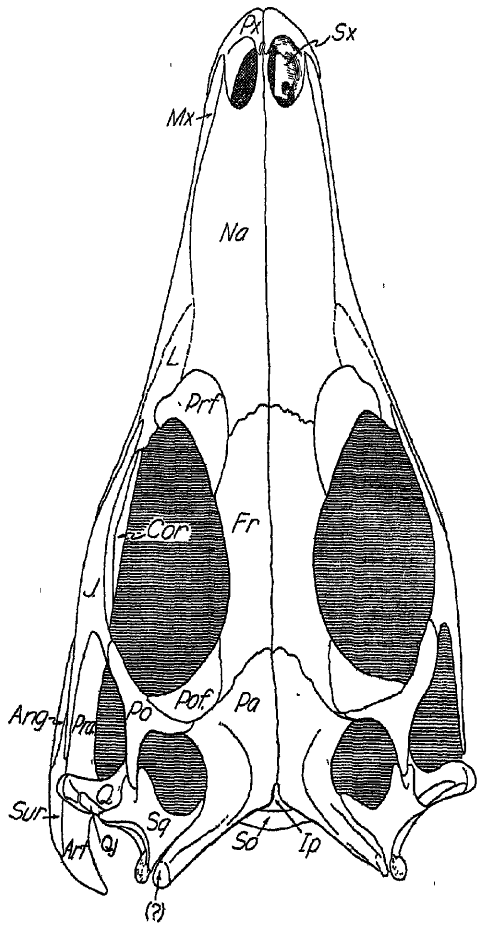


Fig. 2 Dorsal view of skull of *Prolacerta broomi*, x2. Reconstructed. Septomaxillary (Sx) omitted from the left naris.

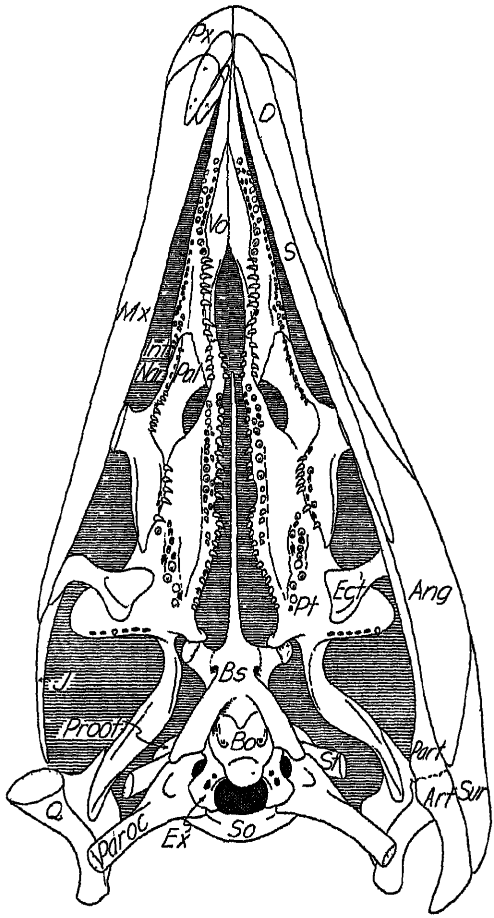


Fig. 3. Palatal view of skull of *Prolacerta broomi*, x 2. Reconstructed. Teeth on px. and mx. are not shown.

the alveoli. The young teeth lie loosely within the alveoli. This condition might be called pleurothecodont as it seems to be intermediate between the strictly thecodont and pleurodont types.

The right SEPTOMAXILLARY (os concha) is a thin, saucer-shaped bone resting on the floor of the external naris and above the suture between the maxillary and premaxillary, (Text Fig. 2). Posteriorly it bears a round notch and the maxillary border is upturned to form an irregular trough. Length 5 mm. width

2 mm. The bone questionably identified as septomaxillary by Parrington is a little larger and lies much farther back.

The MAXILLARIES are long and slender, forming about one-third of the lateral area of the rostrum. The posterior extension underlies the anterior process of the jugal. The nasal and lacrimal sutures are obscure. There are fourteen teeth on the right side and sixteen on the left. In addition there seem to be seven empty alveoli on the left and ten on the right. The teeth are small, slightly compressed and recurved at their tips. Length of longest teeth 2.5 mm.

The NASALS are exceedingly large and are separated by a midline suture. They entirely enclose the borders of the nares. The crushed anterior spines of the nasals appear to have formed at least half of the internarial bar. The nasals form a thin hemicylinder anteriorly where the thin bone has been fractured along the midline, (Pl. 1 and Text Fig. 2).

The FRONTALS are almost exactly as figured and described by Parrington. They are slightly arched over the orbits and the two elements form a shallow longitudinal trough on the midline of the skull roof. The ventral surfaces contain a shallow groove for the olfactory tract. The median suture is complete. There is no median foramen, the hole noted by Parrington is possibly a bite wound.

The PARIETALS are separated by a posterior notch which possibly contained the parietal organ. The only other evidence of a pineal foramen is a slight depression just in front of this notch. The scars of the temporal muscles approach the midline. The posterior arms are somewhat longer than figured by Parrington and are evidently complete. They were transversely severed along a crack in the nodule.

The presence of an INTERPARIETAL may be questioned. There are two slivers of bone intercalated between the right parietal and the thick upper rim of the supraoccipital just lateral to the posterior end of the mid-parietal suture. These may be parts of a vestigial interparietal. They were observed after removing the dislocated supraoccipital which has now been restored to its original position, as found in the matrix, (Text Fig. 5).

Under the name "SUPRATEMPORAL," Parrington describes a "wedge of bone similar to that in *Youngina*," lying between the tip of the left parietal and the squamosal. This is the position of the element which Williston and Broom have called tabulare in the lizards. In our specimen the squamosal has been

separated from the parietal on each side and there is no trace of another bone between them. It seems probable that the supratemporal of *Youngina* and its relatives has become fused with the squamosal in *Prolacerta*.

The supratemporal may, however, be represented by a small, flattened piece attached to the extreme posterior tip of each parietal, and apparently separate from the parietal. This tiny flake lies in front of the posterior border of the parietal, so it could scarcely be the tabulare of pelycosaurs (Parrington 1937). At best its recognition is extremely doubtful and possibly the tips of both parietals are fractured, (Text Fig. 5).

The PREFRONTALS are thick, flattened above, and each has a stout ventral projection which borders the anterior margin of the orbit.

The LACRIMALS are of doubtful extent because of crushing. It appears that the naso-lacrimal suture may have been the breaking point when the skull was crushed. If this were so the area of the lacrimals over the side of the face above the maxillaries was about equal to the area of the prefrontals on the skull roof. All this is supported by the lack of any visible small lizard-like lacrimals and also by the fact that there is a longitudinal canal in the orbital margin of this large broken element, lying medial to the anterior tip of the jugal.

The POSTFRONTALS are discreet and shaped as in primitive reptiles, forming a triangular patch over the border of the orbit. They do not have an extended posterior process.

The POSTORBITALS have a short squamosal process and a very long jugal process. The postfrontal suture is smooth.

The JUGAL retains an attenuated posterior process which extends to within two millimeters of the base of the quadrate and ends in a needle-like point. The anterior (suborbital) process is also long and slender, conforming to the great size of the orbit. The extremity lies along the posterior process of the maxillary and enters a groove in the side of the lacrimal. The shorter dorsal (postorbital) process is inserted medial to the descending arm of the postorbital. There is no possibility of a sutural union between the jugal and the quadratojugal, but there may have been a ligamentary connection.

The bone identified by Parrington as QUADRATOJUGAL is present on each side. It corresponds with his description "a slightly curved, rod shaped bone 6 mm. long and rather more than 1 mm. wide and bearing no trace of any anterior projec-

tion or facet for the reception of a posterior projection of the jugal." Its rounded lower end is provided with a longitudinal furrow which rested upon a ledge or shoulder on the outer ridge of the quadrate. Dorsally it must have articulated with the latero-ventral process of the squamosal.

The SQUAMOSALS evidently abutted directly against the posterior arms of the parietal. They now lie separated from the parietals but there is no evidence of an intervening "supratemporal." There is certainly no suture traversing the squamosal. The element is short and massive. Its posterior projection is pressed downward across the head of the quadrate. Its ventral process evidently met the quadratojugal. Its inner prong adjoins the parietal and its broad, short anterior process containing an anterior sutural depression must have underlain the posterior process of the postorbital.

The QUADRATE is high, sickle shaped and not greatly expanded dorsally where it is capped by a process of the squamosal. Its ventral condyle is a simple slightly convex surface transversely elongated. The knife edge projection or ledge accommodating the base of the quadratojugal lies about 4 millimeters above the condyle. The outer rim of the quadrate is a segment of an eclipse which evidently carried a tympanic membrane about 8 mm. in vertical diameter.

The quadrate in the lateral view (Text Fig. 1) is seen to be tilted backward and was evidently not fixed in the vertical position as in other eosuchians.

The bones of the palate (Text Fig. 3) are thin and bore about 168 hollow teeth fused to the edges of shallow pits. Some of the empty pits are much larger than the bases of the large teeth. The internal nares are laterally placed, narrow, elongate and simple They are bounded by the palatines, vomers and premaxillaries. They extend rather far back. The interpterygoid space is narrow. The post-palatine (ectopterygoid) fenestra is laterally placed. The pterygoid-ectopterygoid flange, which controls the alignment of the lower jaws in most reptiles, is poorly developed.

The VOMERS (=prevomers of Broom) are visible except for their extreme tips. They are crushed slightly out of position but they evidently met on a midline suture in the anterior half of their extent. There was evidently an oval space between them posteriorly. There is a rounded external ridge which defines the median margin of the internal naris. The anterior

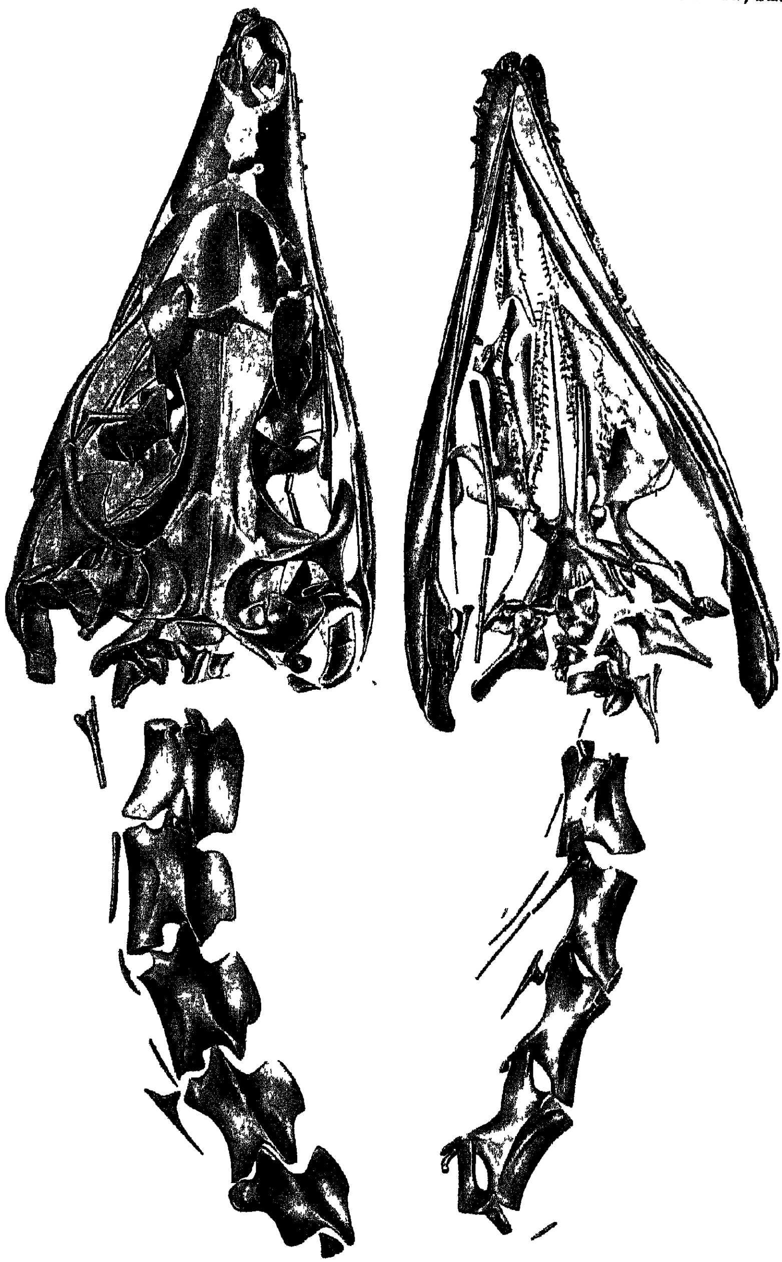


PLATE I.
Plate I *Prolacerta broomi,* U. C. Mus. Pal. no. 37151, x 1-½.

end of this ridge bears a double row of small teeth, about sixteen on each side. These alternate with each other in the double row. There are about eighteen teeth on the posterior part of the external ridge. The inner margin of the widest part of each vomer bears a single row of eleven to twelve of the largest and sharpest teeth on the palate. These project downward so far that they would seem to have interfered with the use of the tongue. Possibly the tip or tips of the tongue lay behind or lateral to these teeth.

The PALATINES are apparently shorter than in *Youngoides*, (Olson 1936). The slender anterior and posterior processes join to form a pedestal with a broad foot abutting against the maxilla. The anterior process enters a notch in the prevomer near the tip of the pterygoid. It bears a single longitudinal row of eleven to thirteen small, slender, slightly recurved teeth. Slightly larger, blunter teeth are set along the inner margin of the posterior process; nine on the right and fourteen on the left. This process broadens out posteriorly to form the anterior margin of the ectopterygoid fenestra but it does not reach the ectopterygoid bone. A small fenestra seems to have been present between the pterygoids and palatines.

The PTERYGOIDS are similar to those of *Youngoides* as figured by Olson (1936). They are extensive, reaching the vomers anteriorly as in *Stenaulorhynchus* and *Sphenodon*, and sending out a broad transverse process to join the ectopterygoid. The posterior margin of this process bore six small pointed teeth. The flattened quadrate process is elongate and slides up below the broad dorsal inner (anterior) flange of the quadrate. The inner margin of the anterior process bears three longitudinal rows of thickly set pointed teeth. I count fifty of these on the right side. Joining these in front of the basipterygoid articulation is another shorter double row of fairly large teeth set on a ridge which runs forward toward the tooth row on the palatine bone. There are twelve teeth (including empty alveoli) on each side in this series.

An element, evidently the displaced left ECTOPTERYGOID, lies inside the outer margin of the left orbit. It consists of a short rod with a flattened outer tip and a much broadened inner extremity which lies on the broad, concave forward surface of the transverse process of the pterygoid. The right ectopterygoid also lies approximately in this position.

The left EPIPTERYGOID is visible within the posterior margin of the orbit, below the postorbital. It is stouter than in modern lizards and has a broad foot. The foot has evidently been broken away from a long quadrate process of the epipterygoid, which ran toward the quadrate along the medial side of the quadrate process of the pterygoid. The upper end of the right epipterygoid may be seen within the supratemporal fenestra.

The SUPRAOCCIPITAL is crushed and broken. Its thick dorsal border lies beneath the parietals and sends out a thin shelf, convexly curved, over the foramen magnum. This shelf thickens at the side to enclose the dorsal parts of the upper canals of the inner ear.

The EXOCCIPITALS have been pressed out of position and now lie on each side of the occipital condyle in the plane of the basioccipital. An extensive foot rested upon the basioccipital, and a cup at the dorsal end received the dorsal head of the paraoccipital. The ventral head of the paroccipital engaged the lateral margin of the foot of the exoccipital. Between these parts was a large foramen, doubtless for Nerves IX, X and XI, as in phytosaurs and *Iguana*. There is one large and one small foramen in the posterior face of each exoccipital. These pass completely through the bone and probably carried Nerve XII, as in primitive lizards and many other reptiles.

The posterior nerve exits in lizards are variously arranged. In *Varanus* and the mososaurs, Nerve IX has a separate foramen through the paroccipital bone. Nerves X and XI have a common inner foramen lying between the paroccipital and exoccipital bones. Nerve XII passes into this large foramen through the two inner foramina in the exoccipital. In a previous description of *Varanus* (Camp, 1942, p. 39, second paragraph) a line was unfortunately omitted, including a statement concerning the exits for Nerve XII. The true state of affairs may be seen in Fig. 19 of that paper. The statement should read: "Nerve XI enters the brain case through the foramen magnum, turns back, and joins Nerve X and passes out through their common foramen. Nerve XII issues from the brain into two small foramina in the exoccipital bone . . ."

The PAROCCIPITALS are separated from the exoccipitals similarly on each side of the skull, (Text Fig. 5). There can be little doubt of the persistence of an exoccipital suture: a primitive condition. The quadrate arm of the paroccipital probably

articulated loosely with the back of the quadrate near its head, and did not reach the squamosal.

The BASIOCCIPITAL is relatively narrow and thick, with bifurcate anterior wings bearing tubera at their bases. These are traversed vertically by a canal. The condyle is hemispherical. The element now lies separated from the basisphenoid and the latter shows a broad, longitudinally grooved, horizontal sutural surface which overlapped the anterior edge of the basioccipital.

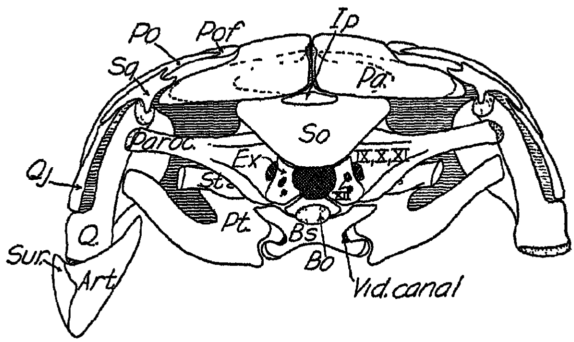


Fig. 4. Rear view of skull of *Prolacerta broomi*, x 2. Reconstructed.

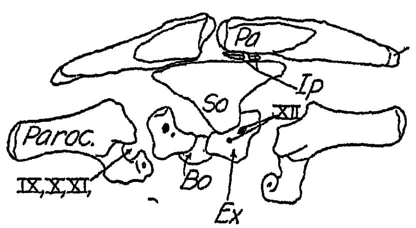


Fig. 5. Rear view of skull elements of *Prolacerta broomi*, U.C. Mus. Pal. no. 37151, x 2.

The posterior-shaped wings of the BASISPHENOID are produced into rods each of which terminates in a cup-shaped articular surface; and this evidently articulated with a rounded condyle on the paroccipital. The lateral wings carrying the basipterygoid processes are fused to the basisphenoid but traces of sutures appear between the bases of the processes and the parasphenoid part of the basisphenoid. The Vidian canal penetrates these old sutures. In *Youngoides*, according to Olson (1936), the sutures are still open.

The PARASPHENOIDAL ROSTRUM is extremely attenuate. It extends forward nearly as far as do the pterygoids. The rostrum is thick at its base where it is excavated dorsally into a trough. There is no trace of a separate presphenoid. This element may be fused to the upper margin of the parasphenoid because there seems to be a trace of a suture between the basisphenoid and the upper margin of this rostrum. Length of para-basisphenoid along midline: 27 mm.

The PROÖTIC is a massive, complex element separated from the paroccipital by smooth sutures and displaced from it on both sides of the skull. On the left side the shallow trigeminal notch is visible behind the orbit, and below there are two stout pedestals, one for the paroccipital and the other evidently for articulation with the basisphenoid. There was a sharp lateral wing or ridge on this bone something like that found in *Varanus* and other lizards, where a similar ridge (crista proötica) forms a channel for the outer course of the VII nerve.

There are no visible traces of orbitosphenoidal (=postoptic) and septosphenoidal elements (cf. Camp 1942).

A rod-shaped bone appears on the right side of the palate and extends transversely from slightly above the basioccipital to a point just beyond the tip of the posterior arm of the basisphenoid. This is probably the right STAPES. The median end is expanded horizontally, but the foramen, if present, cannot be seen. The outer end is compressed antero-posteriorly and must have been continued several millimeters in cartilage, to the tympanum. Length of stapes: 5.5 mm.

Series of thin, widely overlapping SCLEROTIC plates lie above the pterygoids and below the frontals and prefrontals in both orbits. Four of the posterior sclerotics may be seen in the left orbit and a series of six or seven of the upper ones are preserved in the right orbit. The eye was exceptionally large. The plates doubtless served to preserve its sphericity. Their shape cannot be accurately determined but from what remains they appear to resemble the sclera of *Sphenodon*.

The lower jaws are unfenestrated. The bones are splint-like and are exceedingly weak and slender (Pl. 1 and Text Figs. 1 and 3). The symphysis was apparently ligamentous as the rami are now slightly separated and show no terminal sutural serrations.

The right DENTARY is short and thin, and bears seventeen visible pleuro-thecodont teeth. These are barely recurved, slightly compressed and in the main alternate with those of the somewhat larger teeth in the upper jaw.

The ANGULAR forms one-half of the lower border of the jaw. It wedges between the dentary and splenial and fades out beneath the glenoid.

The SURANGULAR is also elongate. It barely meets the dentary and extends back to a point midway between the glenoid and the tip of the articular. The usual foramen for the mandibular nerve traverses the surangular, emerging at point just below the glenoid and a shallow groove continues backward from this exit.

The ARTICULAR seems to be separated from the prearticular by a questionable suture in and below the center of the shallow glenoid. It continues backward to form the long hookshaped upturned digastric process.

The PREARTICULAR is expanded at the glenoid, thins out and expands again into a broad plate covering the inner face of the ramus forward to the splenial.

The CORONOID is seen principally on the inner face of the ramus above the prearticular and runs obliquely down lateral to the splenial. The coronoid process is a mere vestige.

The SPLENIAL is the largest and longest element in the jaw, extending from the symphysis to beneath the center of the orbit and forming most of the inner face of the ramus for that distance.

Elements of the HYOID APPARATUS are seen below the palate. A pair of slender elongate rods extends from the mid-pterygoid region toward the inner faces of the quadrates. Parrington's specimen shows one of these and he identifies it as a ceratohyal. The first ceratobranchial is the element usually ossified in lizards, and that must be the condition here in *Prolacerta*. In the mosasaurs (Camp 1942, Fig. 23) the epihyal also appears to be ossified; that is not probable here. Among modern Iguanidae and Agamidae there are some genera with large, curved ceratobranchials accompanying a throat pouch, (cf. Camp 1923, Fig. 29, *Brachylophus*).

Two short rods lying lateral to the tip of the left ceratobranchial may represent the first and second epibranchials. The larger rod lying beneath the bend in the right ceratobranchial may be the base of the first epibranchial.

If these identifications are correct a reconstruction of the hyoid apparatus might have been approximately as in Text Fig. 6. A moderately extensible tongue was probably present as in the most primitive modern lizards, and *Sphenodon*. The completeness of the third arch is of course doubtful. The

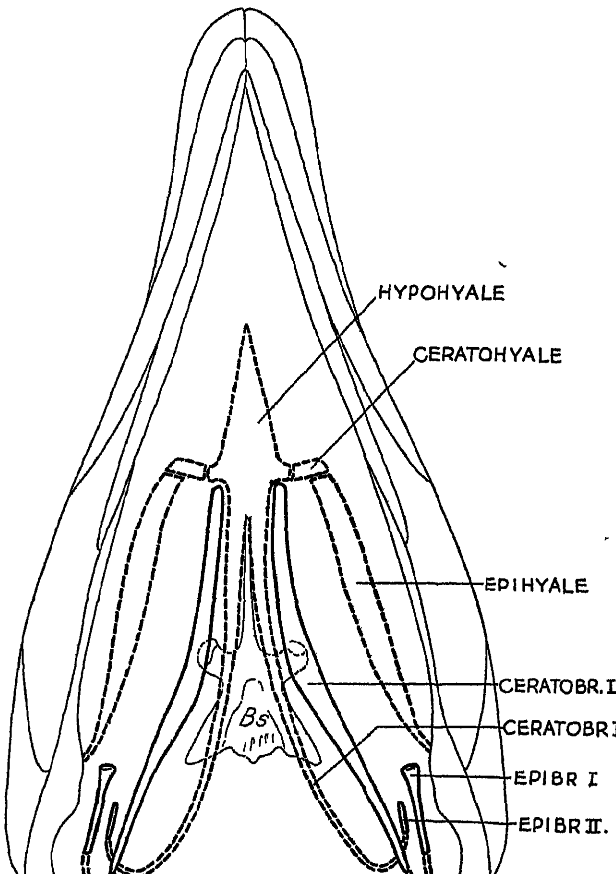


Fig. 6. Hypothetical restoration of hyoid of *Prolacerta broomi*, x 2. Solid elements represent elements preserved in the specimen.

processus lingualis may have been short and broad as in *Sphenodon* (Furbringer 1922, Fig. 5), for the distribution of the palatal teeth would seem to indicate a short tongue.

Cervical vertebrae.—Six cervical vertebrae are preserved in

series behind the skull. These are relatively much larger than in *Sphenodon* and modern lizards, indicating a strong, elongate neck, probably arched upward and carrying the head rather high. Possibly the long, strong neck accompanying a narrow pointed skull indicates aquatic habits.

Centra long, non-tapering, shallowly biconcave. The persistence of chorda is shown by the presence of pits in the articular faces of the centra. There is a sharp ridge beneath the entire length of each centrum, giving the cross sections a triangular outline. Zygapophyses exceptionally large, their facets nearly horizontal in the mid-cervical region; facets becoming more and more oblique anteriorly; neural spines low, compressed and nearly as long as the centra; no sutures between neural arches and centrum.

The ATLAS complex has been crushed and dissociated. My interpretation of the parts is none too certain. The right neural arch now lies just behind the supraoccipital. Its inner (medial) surface appears in the dorsal view. The neck of this bone contains a foramen, its foot is an articular surface, and now points forward. Its posterior zygapophysis is broken away and lies against the right prezygapophysis of the axis. A small, flattened, slightly bowed element to the right of the neural arch may be the right PROATLAS.

The left neural arch lies against the posterior face of the extremity of the left parietal. In this position it might be taken for a tabular but it has an articular foot and foramen as in the opposite bone. A smaller flat, bowed element lying beneath the extremity of the parietal is possibly the left proatlas. It might be regarded as a displaced supratemporal, but again this is highly improbable.

The ODONTOID is a relatively small, elliptical spheroid lying beneath the anterior end of the left atlantal arch. There are shallow lateral furrows for the articulation of the feet of the neural arches. The odontoid was evidently not fused with the centrum of the axis.

The INTERCENTRA of the atlas and axis lie together behind the occipital condyle. The atlantal intercentrum is slightly smaller than the axial and neither of them bears hypapophyses or keels. The intercentrum lying beneath the posterior end of the centrum of the third vertebra is a small crescentic nodule that could be regarded as the hypapophysis of the third cervical.

The AXIS is shorter than the other cervicals, but its neural spine is longer and higher. Prezygapophyses are present and there is a sharp sub-central keel. The anterior condyle is smooth, slightly convex and shows no trace of fusion with the odontoid. Centrum 9 mm. in length.

The THIRD and FOURTH cervicals are the largest of the series as preserved. Ventrolaterally each centrum has a slight constriction, or muscle scar, bounded above by an arched ridge. Length of centrum of third cervical, 11 mm.; of fourth cervical, 12 mm.; of fifth cervical, 11 mm.; of sixth cervical, 10 mm.

Cervical ribs.—Remains of cervical ribs adjoin the six anterior vertebrae. Ribs were evidently present on all the cervicals. A fragment of a slender hairlike atlantal rib lies beneath the left neural arch of the atlas. This rib was about 20 mm. in length and only one-third of a millimeter in diameter. A slightly larger dichocephalous rib is appressed to the right side of the axis. Its length is approximately 24 mm. and its width about half a millimeter. The width of the head and tubercle together is slightly more than one millimeter. The left axial rib is also present. The third right cervical rib bears a ventral keel beneath the head and tubercle. The width of this expanded part is about two millimeters and the incomplete length, as exposed, is thirteen millimeters. The fourth right cervical rib is stouter and was evidently shorter. It is boat shaped with an anterior spine nearly two millimeters long. The head and tubercle bear convex facets only one-half a millimeter apart. The tubercle which articulated with the facet on the lower border of the anterior face of the fourth centrum is larger than the head which evidently articulated with the fourth intercentrum. Both facets are convex. The fifth left cervical rib is like the fourth but larger, the width of the expanded part being about three millimeters, and the exposed length 8 mm. The facet on the tuberculum is concave. The articular extremity of the sixth right cervical rib bears a short anterior spine, a large tuberculum with a concave facet and a long slender head.

(*To be concluded.*)

SCIENTISTS RECENTLY STARRED

In Geology, Physics, Chemistry, Mathematics and Astronomy.

Stephen S. Visher.

ABSTRACT Of the 246 men and four women first starred by secret vote of their fellow scientists in the seventh edition of American Men of Science (1944), 141 men and one woman are in the five sciences here considered. Their names, distribution by institutions, and place of undergraduate and doctoral training are given, and something as to their birthplaces. Some statistical data are given also for the groups first starred in 1932 and 1937. Tables I and II summarize for the more important institutions in these fields, the data as to distribution, and place of doctoral training. The median ages at starring for the 1943 groups are: Astronomy 36, Mathematics 37, Physics 40, Chemistry 43, Geology 44.

As a supplement to a study in The American Journal of Science in 1939[1] the following report upon these scientists first starred in the seventh edition of *American Men of Science* is of interest. Here they are listed, their distribution by institutions given, and the place of collegiate and doctoral training, and birthplace. For each of the five sciences some data are also given for those starred in 1932 or 1937 or earlier. The total number of starred scientists listed as connected with specified institutions is only approximate because some have shifted since the data were assembled.

Table I summarized for the institutions having most scientists of these sorts the data given beyond in more detail for each of the five sciences. It reveals that of the persons (only one woman was starred in 1943 in these five sciences) first starred in 1943, Columbia and Harvard each have 10, California 9, Massachusetts Institute of Technology (M. I. T.) 8, Chicago 7, Michigan 5, Princeton 5, Stanford 4. Of those starred in 1932, 1937 or 1943, Harvard has 25, California 25, Princeton 21, Columbia 19, Chicago 17, Michigan 17, Massachusetts Institute of Technology 17, California Institute of Technology 17, Yale 12, Illinois 10, Stanford 10, Cornell 9, Hopkins 8, Wisconsin 6, Minnesota 5.

[1] Distribution of the younger starred scientists, especially those in the physical sciences. Amer. Jour. Sci. Vol. 237: 48-65, Jan. 1939.

Am. Jour Sci.—Vol. 243, No. 1, January, 1945.
3

Table I discloses that of starred *geologists*, the federal government (chiefly the U. S. G. S.) has most. The three leading universities are Chicago, Columbia and Yale. Of the younger starred *physicists* Massachusetts Institute of Technology and California Institute of Technology have the largest number followed by Michigan, Princeton, California, Harvard, Chicago, and Columbia. Of the younger starred *chemists* the largest groups are at California, Chicago, Columbia, Illinois, Massachusetts Institute of Technology, Michigan, Princeton, and Stanford. As to *mathematicians*, the leading institutions are Harvard, Princeton, Columbia and the Institute for Advanced Study (at Princeton). As to *astronomers*, Mount Wilson Observatory of the Carnegie Institution leads, followed by Chicago, California and Harvard.

TABLE I. Distribution by Chief Institutions of Recently Starred Men.

	Geology		Physics		Chemistry		Math.		Astron.	
Starred In:	'43	'32-'43	'43	'32-'43	'43	'32-'43	'43	'32-'43	'43	'32-'43
California	2	4	2	6	3	9	1	1	1	4
Calif. Tech.	0	2	2	9	0	4	0	1	1	1
Carnegie Inst.	3	5	1	2	1	2	0	0	2	8
Chicago	2	4	1	3	1	4	0	1	3	6
Columbia	3	5	1	4	3	6	1	3	1	1
Cornell	0	0	1	4	1	4	1	1	0	0
Harvard	1	2	2	5	4	7	2	7	1	4
Hopkins	0	1	0	3	0	3	0	2	0	0
Illinois	0	1	1	2	1	5	1	2	0	0
Mass. Tech.	1	1	5	12	2	3	0	1	0	0
Michigan	0	1	2	7	2	5	0	1	1	2
Minnesota	1	1	1	1	1	2	0	0	0	1
North Carolina	0	0	0	0	0	0	2	2	0	0
Northwestern	0	0	0	0	2	3	0	1	0	0
Ohio	0	0	0	2	1	2	0	1	0	0
Pennsylvania	0	0	1	1	2	2	0	1	0	0
Princeton	0	2	1	6	1	6	2	4	1	3
Rockefeller	0	0	0	0	1	5	0	0	0	0
Stanford	0	0	2	3	2	5	0	2	0	0
U. S. Federal	7	19	0	4	1	5	0	0	1	2
Virginia	0	0	0	0	0	0	1	3	1	1
Wisconsin	0	0	1	1	1	2	0	3	0	0
Yale	1	3	1	2	0	3	0	1	1	3

Table II summarizes the distribution of doctoral training by leading institutions. It reveals that for these five sciences combined the leaders for those starred 1932-1943, are California 43, Chicago 37, Harvard 36, Princeton 28, Yale 27,

California Institute of Technology 19, Hopkins 14, Columbia 13, Illinois 11, Wisconsin 11, Massachusetts Institute of Technology 9.

As to *geologists*, Yale leads, followed by Chicago and Harvard. As to *physicists*, California Institute of Technology and Princeton lead, followed by Chicago. As to *chemists*, California, Harvard and Illinois lead, with five other universities not far behind Illinois, (California Institute of Technology, Chicago, Columbia, Massachusetts Institute of Technology, Princeton, Wisconsin and Yale). As to mathematicians, Harvard is far ahead, followed by Chicago and Princeton. As to *astronomers*, California leads, followed by Chicago, Princeton and Virginia.

The number of newly added starred men reflects a number of conditions, one of which is the number of somewhat older men on the staff. Some strong departments have a number of men starred in 1921 or 1927 who are still active.

The number of doctoral graduates starred in 1943 as compared with the number starred in 1932 or 1937 reflects changes of significance.

TABLE II. Doctoral Training of Recently Starred Scientists, Leading Universities.

	Geology		Physics		Chemistry		Math.		Astron.	
Starred In:	'43	'32-'43	'43	'32-'43	'43	'32-'43	'43	'32-'43	'43	'32-'43
Brown	0	0	0	0	2	4	1	1	0	0
California	2	6	1	6	7	20	0	1	2	9
Calif. Tech.	0	0	5	10	2	7	0	1	1	1
Chicago	2	11	4	8	0	7	0	5	1	5
Columbia	1	2	0	5	0	7	0	1	0	0
Cornell	0	1	0	3	0	3	0	0	0	0
Harvard	5	11	1	2	6	13	2	10	0	0
Hopkins	1	6	1	7	0	1	0	0	0	0
Illinois	0	1	1	1	4	10	0	0	0	0
Mass. Tech.	1	1	1	8	3	5	0	0	0	0
Michigan	0	0	1	8	1	3	0	0	0	1
Minnesota	1	2	3	4	0	1	0	0	0	1
Ohio	0	0	0	0	2	8	0	0	0	0
Pennsylvania	0	0	0	1	0	0	0	1	0	0
Princeton	1	2	0	11	2	7	3	6	1	4
Stanford	1	2	1	2	0	0	0	0	0	0
Virginia	0	0	0	2	0	0	0	0	1	3
Wisconsin	1	1	2	3	4	6	0	2	0	0
Yale	6	15	2	5	1	6	0	0	1	1

GEOLOGISTS.

First Starred in 1943.

Present distribution by institutions:

U. S. Geological Survey: Bridge, Josiah, Burbank, W. S., Griggs, D. T., King, P. B., Mertie, J. B., Waters, A. C.; *Carnegie Institution*: Ingerson, F. E., Schairer, J. F., Tunell, G.; *Columbia*: Kay, G. M., Kerr, P. F., Shand, S. J.; *California*: Anderson, C. A. Williams, H.; *Chicago*: Croneis, C. G., Krumbein, W. C.; *Arizona*: Short, M. N.; *Harvard*: Billings, M. P.; *Massachusetts Institute of Technology*: Newhouse, W. W.; *Minnesota*: Gruner, J. W.; *Washington* (Seattle): Weaver, C. E.; *Rensselaer*: Hotchkiss, W. O.; *Yale*: Flint, R. F.; *American Museum of Natural History*: Simpson, G. G.; *U. S. National Museum*· Cooper, G. A.; *Consulting*: De Golyer, L. E., Levorson, A. I., Sales R. H.

Academic Training:

Doctorate:

Yale: Cooper, Ingerson, King, Schairer, Simpson, Waters; *Harvard*: Billings, Croneis, Griggs, Short, Tunell; *California*: Anderson, Weaver; *Chicago*: Flint, Krumbein; *Columbia*: Kay; *Hopkins*: Mertie; *Massachusetts Institute of Technology*: Burbank, Newhouse; *Minnesota*: Gruner; *Princeton*: Bridge; *Stanford*. Kerr; *Wisconsin*: Hotchkiss; *Liverpool*: Williams; *St. Andrews*: Shand.

Collegiate:

Yale: Schairer, Simpson; *California*: Short, Weaver; *Chicago*: Flint, Krumbein; *Cincinnati*: Bridge; *Colgate*. Cooper; *Denison*: Croneis; *Harvard*: Billings, Tunell; *Hopkins*: Mertie; *Iowa*: Kay, King; *Massachusetts Institute of Technology*: Burbank; *Minnesota*: Levorsen; *Montana State College*: Sales; *New Mexico*: Gruner; *Occidental*: Kerr; *Ohio*: Griggs; *Oklahoma*: De Golyer; *Pennsylvania State*: Newhouse; *Pomona*: Anderson; *Simmons*: Ingerson; *Washington* (Seattle): Waters; *Wisconsin*: Hotchkiss; *Britain*: Shand, Williams.

Birthplaces: Midwest 11, Northeast 7, Pacific 3, South 2. Canada 1, England 1, Scotland 1, Germany 1.

Distribution of those Starred 1932-1943.

U. S. Geological Survey 19, Carnegie Institution 5, Columbia 5, Chicago 4, Yale 3, California 4, Harvard 2, California Institute of Technology 2, Princeton 2.

Doctorates of those Starred 1932-1943.

Yale 15, Chicago 11, Harvard 11, California 6, Hopkins 6, Columbia 2, Minnesota 2, Stanford 2, European Universities 7.

College degrees of those starred 1932-1943.

Chicago 8, Harvard 8, Yale 5, California 5, Denison 3, Hopkins 3, Iowa 3, Kansas 2, Minnesota 2

Birthplaces of those starred 1932-1943.

Number and, in ( ), approximate yield per million population at median date of birth.

Midwest 20 (1), Middle Atlantic States 12 (1), Pacific States 10 (5), New England 9 (2), South 8 (.4), Mountain States 2 (2), Canada 3, Britain 2, Continental Europe 5.

PHYSICISTS.

Those First Starred in 1943.

Present distribution by institutions:

Massachusetts Institute of Technology: Alvarez, L. W., Evans, R. D., Nottingham, W. B., Ridenour, L. N., Stratton, J. A.; *Bell Laboratory*: Kelly M. J.; *Brown*: Brillouin L; *California*: Jenkins, F. A., McMillan, E. M.; *Californa Institute of Technology*: Neddermeyer, S. H., Strong, J. D.; *Carnegie Institution*: Seitz, F.; *Central Science*: Klopsteg, P. E.; *Chicago*: Zachariasen, W. H.; *Columbia*· Fermi, E.; *Cornell*: Rossi, B.; *Duke*: Sponer, A. D.; *General Electric*: Blodgett, K. B.; *Harvard*: Furry, W. H., Hunt, F. V.; *Illinois*· Kerst, D. W.; *Indiana*: Mitchell, Alan; *Institute for Advanced Study*: Pauli, W.; *Michigan*: Crane, H. R., Sawyer, R. A.; *Minnesota*: Nier, A. O.; *Pennsylvania*: Harnwell, G.; *Pittsburgh*· Hutchisson, E.; *Princeton*: Wheeler, J. A.; *Purdue*: Lark-Horvitz, K.; *Rochester*: O'Brien, B.; *Stanford*: Hansen, W. W., Kirkpatrick, P.; *Wisconsin*: Herb, R. G.; *Yale*: Margenau, H.

Academic Training:

Doctorate:

California Institute of Technology: Crane, Evans, Mitchell, Neddermeyer, Ridenour; *Chicago*: Alvarez, Jenkins, Kelly, Sawyer; *Princeton*: Harnwell, McMillan, Nottingham, Seitz; *California*: Kirkpatrick; *Harvard*: Hunt; *Hopkins*: Wheeler; *Illinois*· Furry; *Massachusetts Institute of Technology*: Shockley; *Michigan*. Strong; *Minnesota*: Hutchisson, Klopsteg, Nier; *Stanford*: Hansen; *Wisconsin*: Herb, Kerst; *Yale*: Morgenau, O'Brien; *Italy*: Fermi, Rossi; *Cambridge*: Blodgett; *Gottingen*: Sponer; *Oslo*: Zachariasen; *Paris*: Brillouin; *Vienna*: Lark-Horvitz, Pauli; *Zurich*: Stratton.

Collegiate:

Bryn Mawr: Blodgett; *California Institute of Technology*: Crane, Evans, McMillan, Shockley; *Case*: Hutchisson; *Chicago*: Alvarez, Jenkins, Ridenour; *Dartmouth*: Sawyer; *DePauw*: Furry; *Haverford*: Harnwell; *Kansas*: Strong; *Massachusetts Institute of Technology*: Stratton; *Midland*: Margenau; *Minnesota*: Klopsteg, Nier; *Missouri School of Mines*: Kelly; *Occidental*: Kirkpatrick; *Ohio*: Hunt; *Purdue*: Nottingham; *Stanford*: Hansen, Neddermeyer, Seitz; *Virginia*: Mitchell; *Wisconsin*: Herb, Kerst; *Yale*: O'Brien; Foreign 6.

Birthplaces:

New England 1, Middle Atlantic 2, South 3, Midwest 14, Colorado 1, Pacific 6. Austria 2, Germany 2, Italy 2, England 1, France 1, Norway 1.

Physicists starred 1932-1943.

Distribution:

Massachusetts Institute of Technology 11, California Institute of Technology 9, Michigan 7, California 5, Chicago 4, Columbia 4, Cornell 5, Harvard 5, Hopkins 3, Illinois 2, Minnesota 2, Ohio 2, Princeton 6, Stanford 2, Wisconsin 2, Yale 2, Bell Telephone Laboratory 3, Carnegie 2, Federal 4, General Electric 2.

Doctorate:

California 6, California Institute of Technology 10, Chicago 8, Columbia 4, Cornell 3, Harvard 2, Hopkins 7, Massachusetts Institute 2, Michigan 3, Minnesota 4, Princeton 10, Stanford 2, Virginia 2, Wisconsin 3, Yale 5, Germany 14, Other European 7.

Collegiate:

California 6, California Institute of Technology 6, Case 2, Chicago 7, Columbia 3, Cornell 4, Dartmouth 2, Harvard 2, Massachusetts Institute of Technology 3, Michigan 2, Minnesota 4, Ohio 2, Pomona 2, Princeton 2, Stanford 4, Wisconsin 2, Yale 2.

Birthplaces of All Starred Physicists:

Number and, in ( ), approximate yield per million population at about median date of birth.

Midwest 127 (7), Middle Atlantic States 75 (8), New England 63 (18), South 31 (2), West 11 (4). Canada 9, Britain 17, Germany 15, Other Europe 37. Leading American States: New York 48 (10), Ohio 43 (13), Massachusetts 34 (17), California 8 (12), Connecticut 11 (20), *Illinois* 17 (6), *Indiana* 7 (3), *Iowa* 9 (6), Kansas 7 (7), Maryland 7 (7), Michigan 9 (4), Minnesota 7 (6),

Missouri 10 (5), New Jersey 9 (6), Pennsylvania 18 (4), Wisconsin 11 (10). Leading Cities: Baltimore 4, Boston 6, Chicago 5, Cleveland 6, New York 19, Philadelphia 6, St. Louis 4, Washington D. C. 4.

CHEMISTS.

Those First Starred In 1943.

Distribution by Institutions:

Harvard: Bartlett, P. D., Edsall, J. T., Oncley, J. L., Wilson, E. B.; *California*: Branch, G. E., Pitzer, K. S., Rollefson, G. K.; *Columbia*: Cope, A. C., Elderfield, R. C., Mayer, J. E.; *Chicago*: Johnson, W. C.; *Cornell*: Debye, P. J.; *Illinois*: Smith, G. F.; *Massachusetts Institute of Technology*: Hauser, E. A., Huntress, E. A.; *Michigan*: Brockway, L. O., Fajans, K.; *Minnesota*: Smith, Lee J.; *Missouri*: Bent, H. E.; *Northwestern*: Dole, M., Gucker, F. T.; *Ohio*: Brode, W. R.; *Pennsylvania*: Connor, R., Kilpatrick, M.; *Pennsylvania State*: Aston J. G., Fenske, M. R.; *Polytechnical Institute*: Mark, H. F.; *Princeton*: Wallis, E. S.; *Purdue*: Hass, H. B.; *Stanford*: Leighton, P. A. Noller, C. R.; *Wisconsin*: McElvain.

Foundations and Industrial Laboratories:

American Cyanamide: Crossley, M. L.; *Carnegie Institution*: Vickery, H. B.; *Eastman*: Huggins, M. L.; *Ethyl*: Calingaert, G.; *Distilled Products*: Hickman, K. C.; *Merck*: Folkers, K., Major, R. T.; *Monsanto*: Thomas, C. A.; *Nutritional Foundation*: King, C. G.; *Rockefeller*: Stanley, W. M.; *Standard Oil*: Flory, P. J.; *United States Bureau of Mines*: Lewis, B.

Academic Training:

Doctorate:

California: Aston, Bent, Branch, Huggins, Mayer, Pitzer, Rollefson; *Harvard*: Bartlett, Dole, Edsall, Gucker, Leighton, Smith, L. J.; *Illinois*: Brode, McElvain, Noller, Stanley; *Wisconsin*: Connor, Cope, Folkers, Oncley; *Massachusetts Institute of Technology*: Elderfield, Fenske, Huntress; *Brown*: Crossley, Johnson; *California Institute of Technology*: Brockway, Wilson; *Michigan*: Smith, G. F.; *New York University*: Kilpatrick; *Ohio*: Flory, Hass; *Pittsburgh*: King; *Princeton*: Major, Wallis; *Yale*: Vickery; *Cambridge*: Lewis; *London*: Hickmann; *Brussels*: Calingaert; *Heidelberg*: Fajans; *Munich*: Debye; *Vienna*: Hauser, Mark.

Collegiate Training:

Amherst: Bartlett; *Brown*: Crossley; *Butler*: Cope; *California*: Aston, Huggins; *California Institute of Technology*: Mayer, Pitzer;

DePauw: Fenske; *Earlham*: Stanley; *Harvard*: Dole, Edsall; *Haverford*: Gucker; *Illinois*: Connor, Folkers; *Kalamazoo*: Johnson; *Manchester*: Flory; *Massachusetts Institute of Technology*: Huntress, Lewis; *Michigan*: Smith; G. F.; *Nebraska*: Brockway, Major; *New York City College*: Kilpatrick; *Oberlin*: Bent; *Ohio*: Smith, L. I.; *Pomona*: Leighton; *Princeton*: Wilson; *Southwestern*: Oncley; *Transylvania*: Thomas; *Vermont*: Wallis; *Washington* (St. L.): McElvain, Noller; *Washington State College*: King; *Whitman*: Brode; *Wisconsin*: Rollefson; *Dalhousie*: Vickery; *Liverpool*: Branch; *London*: Hickmann; Vienna 2, Germany 2, Brussels 1.

Birthplaces:

East North Central States 16, Pacific 5, Mid-Atlantic 5, New England 3, South 2, West North Central 2, West Indies 2, England 3, Canada 1, Austria 2, Belgium 1, Germany 1, Netherlands 1.

Chemists Starred 1932-1943.

Distribution:

California 9, Columbia 7, Harvard 7, Illinois 7, Chicago 6, Michigan 6, Massachusetts Institute of Technology 5, Princeton 5, Stanford 5, California Institute of Technology 4, Cornell 2, Hopkins 3, Minnesota 3, Ohio 2, Pennsylvania 2, Pennsylvania State 3, Wisconsin 4, Yale 3, Federal Departments 5, Rockefeller 5, Carnegie 2.

Doctorates:

California 20, Harvard 13, Illinois 10, California Technical 7, Chicago 7, Columbia 7, Brown 4, Cornell 3, Massachusetts Institute of Technology 5, Michigan 3, Ohio 3, Princeton 8, Wisconsin 6, Yale 6, Hopkins 1, Minnesota 1, New York University 1, Pittsburgh 1, Rochester 1.

Collegiate:

Amherst 2, Brown 2, Calfornia 7, California Institute of Technology 2, Chicago 7, Cornell 3, DePauw 2, Harvard 5, Illinois 5, Kansas 2, Massachusetts Institute of Technology 4, Michigan 4, Minnesota 2, Nebraska 2, Ohio 2, Pomona 2, Princeton 6, Washington (Seattle) 2, Washington (St. Louis) 3, Wisconsin 2, Yale 3. European 25.

All Starred Chemists.

Birthplaces.

Number and, in ( ), approximate yield per million population at median date of birth.

Midwest 138 (6), Middle Atlantic 109 (10), New England 83 (20), South 39 (2), Mountain States 2, Pacific States 17 (8), Can-

ada 14, Britain 22, Germany 9, Other European 28. Leading U. S. States: New York 65 (12), Massachusetts 52 (30), Ohio 42 (13), Illinois 31 (10), Pennsylvania 30 (7), Connecticut 16 (20), New Jersey 16 (16), Wisconsin 13 (12), California 12 (10).

MATHEMATICIANS.

THOSE FIRST STARRED IN 1943.

Distribution:

Artin, E. (Indiana), Chevalley, C. (Princeton), Doob, J. L., (Illinois), Godel, K. (Institute of Advanced Studies), Hadamard, J. (Columbia), Hedlund, G. A. (Virginia), Hurewicz, W. & Jacobson, N. (North Carolina), Lehmer, D. H. (California), MacLane, S. (Harvard), Menger, K. (Notre Dame), Mises, R. E. (Harvard), Montgomery, D. (Smith), Neugebauer, O. & Polya, G. (Brown), Rosser, J. B. (Cornell), Siegel, C. L. (Institute of Advanced Study), Smith, P. A. (Columbia), Weil, A. (Lehigh), Wilks, S. S. (Princeton), Zygmund, A. (Mt. Holyoke).
Institutions with 2 each: Brown, Columbia, Harvard, North Carolina, Institute of Advanced Study and Princeton.

Doctorate:

Brown: Lehmer; *Budapest*: Polya; *Gottingen*. MacLane, Neugebauer, Siegel; *Iowa*: Montgomery, Wilks; *Harvard*: Doob, Hedlund; *Leipzig*: Artin, *Paris*: Chevalley, Hadamard, Weil; *Princeton*. Jacobson, Rosser, Smith; *Vienna*: Godel, Hurewicz, Menger, Mises; *Warsaw*: Zygmund.
Graduate fellows elsewhere than where doctorate was taken: Chicago 2, Columbia 3, Harvard 2, Cambridge 1.

Collegiate:

Alabama: Jacobson; *California*: Lehmer; *Dartmouth*: Smith; *Florida*: Rosser; *Hamline*: Montgomery; *Harvard*: Doob, Hedlund; *Texas College*: Wilks; *Yale*: MacLane. Foreign, 12.

Birthplaces:

California. Lehmer; *Connecticut*: MacLane; *Florida*: Rosser; *Massachusetts*: Hedlund; *Minnesota*: Montgomery; *New Hampshire*: Smith; *Ohio*: Doob; *Texas*: Wilks; *Austria*: Menger, Mises, Neugebauer; *Czechoslovakia*: Godel; *France*: Hadamard, Weil; *Germany*: Artin, Siegel; *Hungary*: Polya; *Poland*: Hurewicz, Jacobson, Zygmund, *South Africa*: Chevalley.

Mathematicians Starred 1932-1943.

Distribution:

Brown 3, Chicago 2, Columbia 4, Harvard 7, Hopkins 2, Illinois 2, Lehigh 2, Massachusetts Institute of Technology 2, North Carolina 2, Princeton 6, Institute of Advanced Study 4, Stanford 2, Virginia 3, Wisconsin 3.

Doctorates: 1932-1943.

Harvard 10, Chicago 5, Princeton 5, Iowa 2; 1 each at Brown, California, California Institute of Technology, Cornell, Pennsylvania, Rice, Wisconsin. Foreign, (1937, 1943 only) 22.

Collegiate: 1932-1943.

Brown 2, Harvard 7, Washington (Seattle) 2, Yale 2.

Birthplaces, starred 1903-1943.

Number and, in ( ), approximate yield per million population at about median date of birth.

New England 36 (9), Mid Atlantic 44 (4), East North Central 36 (3), West North Central 17 (3), South 13 (1), West 3 (1), Canada 5, Britain 10, Germany 11, Hungary 6, Russia 8, other European 30. Leading States: New York 27 (5), Massachusetts 24 (12), Ohio 14 (5), Pennsylvania 12 (3), Michigan 8 (4), Connecticut 8 (12), Wisconsin 7 (5), Iowa 6 (6), Missouri 5 (2), New Jersey 5 (3), Texas 5 (2), Illinois 4 (1), Indiana 4 (2), Minnesota 4 (4). Cities: Boston and Suburbs 12, New York 12, Chicago 2, Philadelphia 2.

ASTRONOMERS.

First Starred In 1943.

Distribution by Institutions:

Chicago: Chandrasekhar, S., Morgan, W. W.; (Swings, P.) *Carnegie* Mount Wilson Observatory: Minkowski, R., Wilson, O. C.; *California*: Mayall, N. N.; *Columbia*: Schwarzchild, M.; *Harvard*: Whipple, F. L.; *Michigan*: McMath, R. R.; *Princeton*: Rosseland, S.; *Virginia*: Vyssotsky, A. N.; *United States Naval Observatory*: Eckert, W. J.; *Yale*: Spitzer, L.

Doctorate

California: Mayall, Whipple; *California Institute of Technology*: Wilson; *Chicago*: Morgan; *Princeton*: Spitzer; *Virginia*: Vyssotsky; *Yale*: Eckert; *Breslau*: Minkowski; *Cambridge*: Chandrasekhar; *Gottingen*: Schwarzchild; *Liege*: Swings; *Oslo*: Rosseland.

Collegiate:

California: Mayall, Whipple, Wilson; *Chicago*: Morgan; *Oberlin*: Eckert; *Michigan*: McMath; *Yale*: Spitzer; Foreign 6.

Birthplaces:

California: (Wilson), Illinois (Mayall), Iowa (Whipple), Michigan (McMath), Ohio (Spitzer), Pennsylvania (Eckert), Tennessee (Morgan), Belgium (Swings), Germany (Minkowski, Schwarzchild), India (Chandrasekhar), Norway (Rosseland), Russia (Vyssotsky).

Astronomers Starred 1932-1943.

Distribution:

Carnegie, Mount Wilson Observatory 8, California 4, Chicago 6, Harvard 4, Michigan 2, Navy 2, Princeton 3, Yale 3.

Doctorate:

California 10, Chicago 6, Princeton 4, Virginia 3, California Institute of Technology 1, Cornell 1, Minnesota 1, Yale 1.

Birthplaces of all Starred Astronomers.

Number and, in ( ), approximate yield per million population. New England 27 (7), Mid Atlantic 19 (2), North Central 50 (3), South 7 (4), West (3), Canada 4, England 3, Germany 4, Netherlands 4. Other foreign 12. Leading States: Massachusetts 14 (7), New York 12 (2), Illinois 10 (3), Ohio 8 (2), Michigan 7 (4), Minnesota 7 (7), California 6 (6), Missouri 5 (3). Leading Cities: Boston and Suburbs 7, New York City 4, San Francisco 3, Cincinnati 2, Chicago 2.

Indiana University,
Bloomington, Indiana.

EVOLUTION OF THE FACIAL SUTURES IN THE TRILOBITES *LOGANOPELTOIDES* AND *LOGANOPELTIS*.

FRANCO RASETTI.

ABSTRACT. The structure of the Upper Cambrian trilobite *Loganopeltoides* and of the Lower Ordovician *Loganopeltis*, believed to be its descendant, is discussed in relation to the problem of the evolution of the facial sutures in trilobites. The evidence presented confirms the view of modern authors that the post-Cambrian members of Beecher's order Hypoparia, such as the Trinucleidae and the Harpidae, derive from trilobites with dorsal sutures, and hence that their eyes are truly homologous with the compound eyes of other trilobites.

The new genus *Loganopeltoides* is erected for *Conocephalites zenkeri* Billings.

THE importance of the facial sutures of trilobites in connection with their evolution and classification has been realized by all students of this animal group. Nevertheless, conflicting views have been held about the evolution of the sutures. Beecher,[1] who was the first to use the character of the sutures for the subdivision of the subclass of trilobites into orders, believed that the most primitive condition of the sutures was the one attributed to the members of his order Hypoparia. In these trilobites the only cephalic suture present (apart from the hypostomal suture) is a marginal one separating the epistomal plate from the dorsal cephalic shield. According to Beecher's interpretation this suture is to be regarded as homologous with the dorsal suture of ordinary trilobites. Consequently, whenever eyes were present in trilobites assigned to the Hypoparia (such as *Tretaspis* and *Harpes*), these structures could not be homologized with the compound eyes of ordinary trilobites.

Raymond,[2, 3] and later, to a certain extent, Poulsen[4] supported Beecher's interpretation of the sutures and his classification. Many students of trilobite structure, however, while agreeing with Beecher in the essential importance of the sutures for the understanding of the phylogeny of the group, questioned the validity of Beecher's orders, and in particular of the order Hypoparia. This criticism has been formulated by Richter,[5] Swinnerton,[6] and many others. An excellent discussion of the subject and the complete bibliography will

be found in a recent paper by Stubblefield.[7] It is claimed by the above authors that Beecher's Hypoparia constitute an heterogeneous assemblage, and moreover, that the characters of the sutures exhibited by most of its members are rather degenerative than primitive.

Among Beecher's Hypoparia, the agnostids are hardly related to the other supposed members of the order. Resser[8] even doubted whether they are really trilobites. The eodiscids, whenever they possess facial sutures (Pagetiidae) are proparian; nothing is known of the existence of cephalic sutures in the blind forms (Eodiscidae). All other members of Beecher's Hypoparia are post-Cambrian, and are mainly represented by the Trinucleidae, the Raphiophoridae and the Harpidae. Many of these post-Cambrian Hypoparia have eyes, and the blind forms are closely related to genera that possess eyes. Beecher and Raymond designated these structures as "ocelli" and believed that they should not be homologized with the eyes of ordinary trilobites, as they are not situated on the facial sutures. The latter are supposed to be represented by the marginal suture.

According to the alternative view, upheld by Swinnerton[6], Reed,[9] Richter,[5,10] and others, the post-Cambrian Hypoparia evolved from ancestors possessing the ordinary type of facial sutures. It is assumed that the facial sutures became obliterated, and that the marginal suture was developed secondarily. The eyes of hypoparian trilobites would therefore be truly homologous with the compound eyes of proparian and opisthoparian trilobites.

The latter interpretation appears preferable for several reasons, among which perhaps the most convincing is the fact that unquestioned hypoparian trilobites are first met with in the Ordovician, whereas the Opisthoparia were already well developed in the Lower Cambrian, and the Proparia in the early part of the Upper Cambrian. However, to the writer's knowledge only one example has been put forward as evidence for the evolution of a hypoparian from an opisthoparian trilobite. The case in question is the hypothetical descent of the Trinucleidae from *Orometopus*, suggested by Lake,[11] but questioned by Raymond.[3]

The writer believes to have discovered a more convincing case in the late Upper Cambrian genus *Loganopeltoides* and the early Ordovician genus *Loganopeltis*. The aim of the

present paper is to describe and illustrate the structure of the sutures in these trilobites and to discuss their significance.

LOGANOPELTOIDES, new genus.

The genus is erected for trilobites similar to *Loganopeltis*, but possessing dorsal sutures.

Cephalon with a strongly convex, prominent, conical glabella. Two or three pairs of glabellar furrows, the posterior one curving backwards, the others short. Occipital furrow well impressed, occipital segment simple. Circumglabellar area convex; brim wide, concave, without a well-defined rim. Genal spines absent, unless they were borne by the epistomal plate, which is unknown.

Surface of glabella granulose. Surface ornamentation of brim consisting of irregular, anastomosing radial ridges.

Thorax unknown. Pygidium narrow and long, with a short, conical axis showing a few segments, and flat pleura turning backward and inward, extended into a pair of flat spines.

Genotype. *Conocephalites zenkeri* Billings.

Stratigraphic range: late Upper Cambrian.

LOGANOPELTOIDES ZENKERI (Billings).

Plate 1, Figs. 2-8.

Conocephalites zenkeri Billings, 1860, Canadian Naturalist, 5, p. 305, fig. 4; 1863, Geol. Canada, Geol. Surv. Canada, p. 288, fig. 253. 1865, Geol. Surv. Canada, Pal. Foss., 1, p. 398, fig. 375.
Ptychoparia zenkeri Miller, 1889, N. A. Geol. Pal., p. 565, fig. 1052.
Loganopeltis zenkeri Rasetti, 1943, Jour. Pal., 17, p. 104; 1944, Jour. Pal., 18, p. 248, pl. 38, figs. 27, 28, 47.

A description of this species has been given by Billings and supplemented by the writer. Here we will only add a few remarks regarding the sutures. After the discussion of this species was written,[12] a few well-preserved specimens have become available. One such specimen is a perfect impression of a small cephalon, whose cast is illustrated in Pl. 1, Fig. 2. After careful study of all the material on hand, the author has concluded that the only dorsal suture existing in *L. zenkeri* is a suture running forward and outward from the eye to the margin of the cephalon; i. e., a suture occupying the position of the anterior branch of the facial suture of ordinary trilobites.

In the above-quoted paper, no doubt was left about the

presence of this suture, and the absence of a suture occupying the position of the posterior branch of the facial suture in opisthoparian trilobites. However, it was questioned whether, instead of one, there might not be two closely parallel sutures running forward from the eye. In other words, it appeared possible that *L. zenkeri* was a proparian trilobite, possessing an exceedingly narrow libragene limited by two parallel sutures. The examination of the better-preserved material now available clearly indicates the existence of only one suture.

It must be noticed that this suture presents a peculiar characteristic, which, as far as the writer knows, is not shown by any other trilobite. The facial sutures of trilobites usually do not correspond to elevations or depressions of the shield, but run across furrows and ridges, so that unless the shield has come apart along the sutures before fossilization, the course of the sutures is difficult to detect. In *L. zenkeri*, however, the suture follows the summit of a ridge, i.e., the test on either side of the suture is turned upward. This feature clearly appears both in complete cephala, such as the one figured, and in specimens in which the posterolateral portions of the cephalon have been broken off. Such specimens definitely show the regular outline of the shield in front of the eye, where the break has followed the suture, as contrasted with the irregular fracture back of the eye, where no suture is present.

Formation and locality: Upper Cambrian boulders (*Hungaia magnifica* zone) in the Lévis conglomerate, at Lévis, Quebec.

LOGANOPELTOIDES MINUTUS (Rasetti).

Plate 1, Fig. 1.

Loganopeltis minuta Rasetti, 1944, Jour. Pal., 18, p. 248, pl. 38, fig. 26.

This species was founded on a pygidium. In the Upper Cambrian boulders of the Lévis conglomerate, besides *L. zenkeri*, there occurs the cephalon of another species, which is tentatively assigned to *L. minutus*.

The cephalon differs from that of *L. zenkeri* in possessing a relatively smaller, less convex glabella, and somewhat deeper, pit-like first and second glabellar furrows. The brim is not turned up vertically as in *L. zenkeri*, but has a slightly convex rim.

In this species, there certainly is no suture running backward

from the eye, and there is at least one anterior suture. In this case, however, the possibility of the presence of two closely parallel sutures cannot be excluded. The examination of the almost perfect cephalon figured in Plate 1, Fig. 1, would rather suggest two parallel sutures, as there evidently is a narrow strip, running forward from the eye, on which the test is absent. This might represent a missing libragene, but there is also the possibility that the test on both sides of the suture was turned upward as in *L. zenkeri*, and was broken off in extracting the specimen from the matrix. It seems difficult to decide this point until more material becomes available.

Formation and locality: same as for the preceding species.

LOGANOPELTIS Rasetti, 1943.
LOGANOPELTIS DEPRESSA Rasetti.

Plate 1, Figs. 4-7.

Loganopeltis depressa Rasetti, 1943, Jour. Pal., 17, p. 103, pl. 19, figs. 1-3.

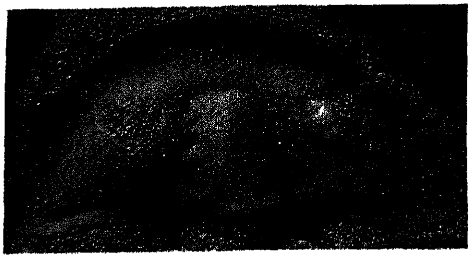
There is nothing to add to the description of this species. Scores of excellently preserved cephala have been examined, and there is no question that, as already stated, dorsal sutures are wholly absent.

Two cephala are illustrated, chiefly in order to show the characters of the eye. There is a well-developed palpebral lobe, and the visual surface is clearly defined, but the facets cannot be distinguished. Notwithstanding the lack of dorsal sutures, the structure of the eye does not appear to differ essentially from that of opisthoparian trilobites.

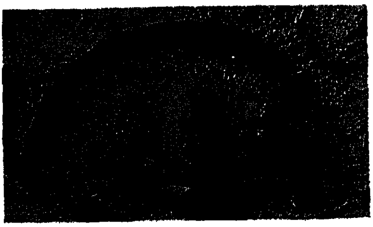
Formation and locality: Lower Ordovician boulders in the Lévis conglomerate, associated with *Leiostegium* sp., *Symphysurina* sp., *Pilekia apollo* (Billings), *Metapliomerops eryx* (Billings), *Kainella orientalis* Rasetti, and other species of early Canadian age; Lévis, Quebec.

DISCUSSION AND CONCLUSIONS.

The first conclusion that may be drawn from the descriptions and illustrations of the trilobites *Loganopeltoides* and *Loganopeltis* is the close affinity between the two genera. The resemblance in all details, excepting the sutures, is striking, especially when one considers the unusual combination of cephalon and pygidium. It seems difficult to deny the relationship between the two genera. Since *Loganopeltoides* is of late Upper Cam-



1



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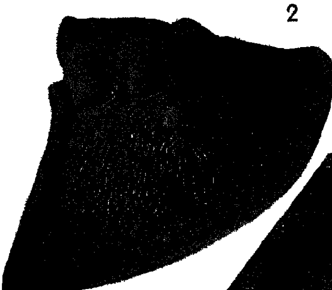

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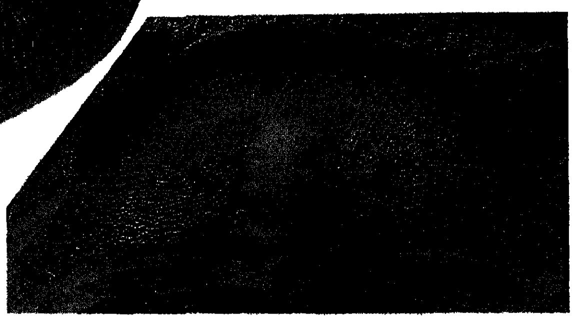

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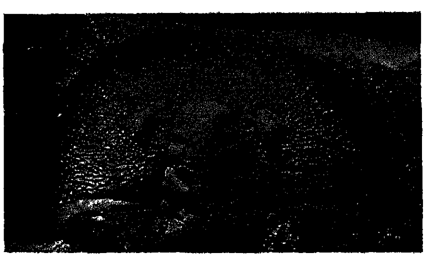

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7

EXPLANATION OF PLATE

Fig 1 *Loganopeltoides minutus* (Rasetti), cephalon, x8, Laval Univ no 1180, plesiotype

Figs 2–3 *Loganopeltoides zenkeri* (Billings) 2, cast of the impression of a perfect cephalon, x4, U S N M no 111725, plesiotype 3, pygidium, x6, Laval Univ no 1181, plesiotype

Figs 4–7 *Loganopeltis depressa* Rasetti 4, side view of a small, perfect cephalon, x6, showing the structure of the eye 5, top view of the same cephalon, x4 6, a larger cephalon, x4 7, pygidium, x6. Laval Univ nos. 1265b–d, paratypes.

brian age, and *Loganopeltis* of early Canadian age, it is likely that the latter is a direct descendant of the former.

Loganopeltoides has dorsal sutures of a very unusual type, i.e., the anterior branch of the facial suture is like that of an ordinary opisthoparian trilobite, but there is no corresponding posterior branch. Two hypotheses might be suggested to account for the lack of a posterior suture: (1) *Loganopeltoides* derives from an opisthoparian trilobite, and the posterior branch of the facial suture is in a state of symphysis; (2) *Loganopeltoides* derives from a proparian trilobite, in which the two branches of the facial suture became closer and closer to each other, until the libragene completely disappeared, the two sutures becoming one (*L. zenkeri*). As discussed above, if this interpretation is correct, *L. minutus* might represent an intermediate stage, in which the two sutures had not quite coalesced into one.

In either case, it is obvious that a suture as present in *L. zenkeri* would be of little use to the animal in ecdysis, and hence would tend to become obliterated by symphysis. This is precisely what the writer believes to have taken place, *Loganopeltoides* having evolved into *Loganopeltis*, in which the dorsal sutures are lacking.

It is also clear that *Loganopeltis*, according to Beecher's classification, would be placed in the Hypoparia. Actually, this genus closely resembles the Harpidae in all respects, and should probably be placed in that family. On the other hand, if our interpretation is correct, this hypoparian trilobite evolved from species that possessed sutures, either of the opisthoparian or of the proparian type. In either case, the evidence presented tends to show that the hypoparian character of the sutures in *Loganopeltis* is not primitive, and there is no particular reason why the same arguments should not apply to other post-Cambrian Hypoparia, such as the Harpidae and the Trinucleidae.

The writer wishes to express his indebtedness to Dr. G. Arthur Cooper for permitting the examination of specimens in the collections of the U. S. National Museum. He is also indebted to Dr. C. H. Kindle for suggesting the possibility that some species of *Loganopeltoides* might possess proparian sutures.

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SCIENTIFIC INTELLIGENCE

Physics and Chemistry.

Experimental Spectroscopy; by R. A. Sawyer: Pp. viii, 323. New York, 1944 (Prentice-Hall, Inc., $4.50).—The English literature on spectroscopy contained several excellent theoretical treatises, but apparently no authoritative exposition, in book form, of modern experimental techniques. This deficiency has been removed by the publication of Sawyer's book.

Starting with an historical introduction to spectroscopy, the author treats in a careful manner first the various appliances of the science and their use, then turns his attention to several specific functions of spectroscopy and shows how they may best be performed. The pages contain a great amount of useful information of a type that can be accumulated only through an experience as long and rich as the author has enjoyed in this field of work.

"The purpose of this book is to discuss prism and grating spectrographs and the techniques of their use in research. It is designed for students of spectroscopy and for those in research laboratories who wish to make use of spectroscopic procedures. For this reason, extensive mathematical treatments have been avoided; a background of general physics and some physical optics should be sufficient for an understanding of the presentation." HENRY MARGENAU.

Chemical Engineering, Nomographs; by Dale S. Davis: Pp. ix, 311; 201 figs. New York and London, 1944 (McGraw-Hill Book Co., $3.50).—The purposes of this publication, as stated by the author in his preface, are (1) to select critically a limited number of nomographs of practical value to the profession, and (2) to present these charts suitably grouped and indexed. The volume seems to accomplish these purposes satisfactorily with the possible exception that the selection was not critical enough. Several of the charts included appear to be of somewhat limited utility.

Many equations which would be of interest are not included in this first edition. Subsequent editions should correct this. However, the inclusion of an equation such as "a Nusselt-type dimensionless equation correlating data for fluids flowing upward at low velocities in vertical pipes" in the heat transfer section is hardly justifiable when the more important Dittus-Boelter equation is omitted.

The volume is well indexed. References are sufficiently complete that the reader can immediately locate the source of any equation appearing in the book. Limitations of the equations are given.

CHARLES A. WALKER.

Magnetochemistry; by PIERCE W. SELWOOD. Pp. ix, 287; 80 figs. New York, 1944 (Interscience Pub. Corp., \$5.00).—In his preface the author of this book mentions that in the nine years since the publication of the works of Van Vleck, Stoner, Klemm, and others, on magnetochemistry over one thousand papers on the subject have appeared. The results of the application of magnetic measurements to the solution of chemical problems are, therefore, certainly deserving of the review and summary which they receive in this book. The book is complete in itself; the principal methods of measurement, the theories involved, as well as the more recent results all receive treatment.

In the first chapter on "Measurement of Magnetic Susceptibility" all the more important types of measurements are discussed. The several simple but clear sketches make immediately apparent the essential features of the Gouy method, the Quincke method, the Faraday balance, the Curie-Chéneveau balance, the Rankine arrangement, etc. No very detailed discussion of any of these methods is given, but copious references to the original literature (here and throughout the book) afford the interested reader all the lead he may need. Atomic and ionic diamagnetism are treated in a short second chapter. The chemist will find more to interest him in Chapter III, "Molecular Diamagnetism." Here the diamagnetic susceptibility of water, important as a standard substance, receives considerable attention. Here also Pascal's constants are discussed and applied. That the diamagnetism of molecular mixtures remains a field open for study is expressed by the author in his refreshing style as follows: "Investigators seem to be divided into three groups, those who find wide positive deviations, those who find wide negative deviations, and those who find the susceptibility to be a strictly linear function of the concentration, all, of course, working with the same solution." Magnetic studies of polymerization, magnetic studies applied to various structural problems, the anisotropy of molecular crystals, and the susceptibility of liquid crystals are discussed. Chapters on atomic and molecular paramagnetism follow. After a theoretical discussion recent measurements of the paramagnetism of many of the metals are summarized. The expanding field of molecular paramagnetism receives considerable attention. The extensive work on the hexa-arylethanes is discussed briefly as are other applications in the field of organic chemistry. A lengthy chapter on complex compounds affords for the inorganic chemist perhaps the most interesting section of the book. The importance of such compounds in biochemistry and in analytical chemistry is brought out by the discussion of the iron complexes. The subjects of metallic dia- and paramagnetism, ferromagnetism, and a chapter on applied magnetometric analysis complete the book.

This monograph should prove valuable as a reference work to those working in the field of magnetochemistry as well as to those seeking to round out their knowledge of chemistry in general. The book manufacture is especially good for one published in 1944.

HENRY C. THOMAS.

GEOLOGY.

Macquarie Island: Its Geography and Geology; by DOUGLAS MAWSON. Pp. 194 (quarto), 46 figs., 37 pls. Government Printing Office, Sidney, Australia, 1943. Price £1.15.0.—Macquarie Island lies between the Tasman Sea and Antarctica, south of a point nearly midway between Tasmania and New Zealand, near latitude 54° 30′ S., longitude 159° E. Its long dimension, extending slightly east of north, measures about 21 miles; the width, remarkably uniform, varies between 1½ and 3 miles; the total area is 46 square miles. Shores of the island are for the most part rocky, and inside a narrow wave-cut bench the borders nearly everywhere rise steeply several hundred feet to a rather subdued plateau surface surmounted by scattered low peaks and dimpled with depressions in which are numerous small lakes. The highest points, in the southern part, are slightly over 1,400 feet above sea level.

Soundings, in connection with isolated islets, indicate that the main island is the summit of a north-south ridge 150 miles or more in length. East of the island the bottom slopes steeply from the 100-fathom line, a mile or two offshore, to considerable depths. On the west, however, an undulating seafloor extends at shallow depth for several miles to the edge of the steep submarine slope. Deep water separates the Macquarie ridge from the Australasian lands to the north.

No attempt at a comprehensive scientific survey of Macquarie was made until shortly before the first World War, when some members of the Australasian Antarctic Expedition spent two years on the island. L. R. Blake, cartographer and geologist of this party, was later killed in action in France. Before he entered the army, however, he turned over to Dr. Mawson his maps, notes, and specimens from the study on Macquarie. These materials supplied the chief basis for the present monograph.

The bedrock consists of mafic igneous rocks, both extrusive and intrusive. A thick series of basaltic lavas forms the oldest exposed unit. This series was invaded by gabbroic masses and some ultramafic dikes, and was severely folded. Erosion exposed the intrusive bodies prior to eruption of another thick succession of basalts and related pyroclastics, the "younger basic group." These later volcanic products were largely of submarine origin, since they are characterized by pillow structure and palagonite, and inclose masses

of consolidated Globigerina ooze. Thus the region has experienced both elevation and depression on a considerable scale.

One of the most interesting geologic aspects of the island lies in the testimony it bears to large-scale glaciation. Glacier ice moved eastward across the entire summit of the island from an area now occupied by deep sea. The extent of the land mass indicated by the glacial evidence can only be conjectured; presumably it had an area vastly larger than the present island. Lithology of the till is for the most part similar to that of the visible bedrock units. However, the till contains also numerous fragments of serpentinized dunite not found in situ. Scattered blocks of sandstone of unknown origin are found also, and two large pieces of granitic rock are of unusual interest in view of the universally mafic composition of the bedrock. However, since both pieces were found near the shore it is possible they were carried from afar by floating ice or even by man.

There is strong presumption that warping and faulting in late geologic time carried most of the former land mass below sealevel. Macquarie Island has the form of an elongate horst, and the steep descent of the seafloor off the east coast suggests a youthful fault scarp. Destruction of the island by wave erosion is proceeding rapidly; however, this process unaided could hardly have consumed a mass several times as large as the present island during the short time-interval since the late Pleistocene. A wave-cut platform, especially pronounced along the northern part of the west coast, stands as much as 40 feet above present sealevel. Seismic disturbances centering in the vicinity of the island have been recorded in recent years.

The writer of the report is to be congratulated on excellent presentation of the data on Macquarie without direct help from the principal field worker. Numerous good halftones give a clear conception of the dominant features of the island. The report includes comprehensive meteorological data and considerable information on the plant and animal life. All of the scientific material has unusual significance, because the island is the only land mass of any consequence in an expanse of ocean much larger than the entire United States. CHESTER R. LONGWELL.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Mitosis, The Movements of Chromosomes in Cell Division; by FRANZ SCHRADER (No. XIV of the Columbia Biological Series), Pp. x, 110. New York, 1944 (Columbia University Press, $2.00). —The brevity of Professor Schrader's treatment of mitosis may come as a surprise to some, but is in keeping with our limited knowledge of the fundamentals thereof. The text has the clarity, incisiveness, and provocative quality that might be expected from

the author. It is not so much a summary as it is a critical inquiry into the problems of mitosis.

A short introductory chapter in which it is made clear that the term "mitosis" is used in the "old, inclusive sense," is followed by a thirty-four page discussion of structural aspects of mitosis in living and fixed cells. The arguments for and against the reality of spindle fibers are carefully weighed in the light of the available evidence. That the spindle has a fibrous structure is conclusively established. The difficulties of observing fibers in the living spindle are chiefly optical and lie in the fact that refractive indices of the spindle substance and the fibers are, in most cases, identical. The nature and origin of the spindle and its relation to central bodies and the chromosomes are carefully treated. Although cytoplasmic elements may be involved, it is clear that the principal spindle elements are nuclear in origin and develop under the influence of the chromosomes. The organization of these elements into the spindle is influenced by the central bodies which are usually extra-nuclear, but are known to be in some way related to the kinetochores. Of the more than 27 terms applied to the spindle attachment region of the chromosomes, Schrader prefers kinetochore.

How the spindle is organized from the nucleoplasm is a basic problem approached in the third chapter on "hypotheses of mitosis," along with the various suggestions as to the mechanism of separation of the chromosomes. Contraction and expansion of fibers, viscosity and hydration, electrostatics, diffusion, streaming, hydrodynamics, are all considered. It is indicated that advances in our knowledge of tactoids offer hope in understanding the structure and functioning of spindles. Emphasis is placed on the increasing evidence of chromosome autonomy in the mitotic mechanism.

In a fourth chapter on related problems, the incompleteness of our knowledge of the properties of the nuclear membrane, the kinetochore, and the fine structure of the chromosome is emphasized. There can be no doubt that a clear understanding of the physical and chemical nature of chromosomes and their reproduction is prerequisite to the full solution of the problem of mitosis.

There is a bibliography of eighteen pages and an index.

D. F. POULSON.

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NOTES ON *THAMNOCRINUS SPRINGERI* GOLDRING AND OTHER HAMILTON CRINOIDS.

WINIFRED GOLDRING.

ABSTRACT. Two young specimens of the camerate crinoid *Thamnocrinus springeri* Goldring have been recently collected, the younger of which preserves the tegmen hitherto unknown. New material permits additional observations on other previously described Devonian (Hamilton) crinoids from New York State.

I. YOUNG FORMS OF THAMNOCRINUS SPRINGERI GOLDRING.

Plate 1, figs. 1-3.

THROUGH the courtesy of Mr. Max J. Kopf of Lancaster, New York, it has been possible to study two young specimens of *Thamnocrinus springeri* Goldring, collected by him in 1942 from the Moscow shale, Livingston county, New York. The younger specimen shows the tegmen, which was not preserved in the cotypes described by the author in the *Devonian Crinoids of New York* (N. Y. State Mus. Mem. 16, 1923, p. 243, pl. 26, figs. 8 to 10). The theca in this specimen has a height of 11 mm. and a diameter across the tegmen of between 11 mm. and 12 mm., indicating a quite young specimen as compared with the mature form which, in the more complete type (*ref. cit.*, figs. 9, 10), shows a height of 17 mm. and a breadth of 20 mm.

The *tegmen* has a distinctly lobed appearance. It is low with depressed interambulacral areas and pronounced ridges marking the ambulacral areas. A large spine (broken stump only left), 2 mm. in diameter at the base, is located between the two main arm divisions in each tegminal axil. It rises from a socket at the end of a protuberance composed of small plates. The interradial depression between each two spines is deep. On each side and forward of this large spine, above each main arm division, is a small spine or spinose tubercle which must develop into the strong spines of the mature form,

giving with the central large spine three spines to the ray. The anus is excentric, at the end of a short tube or protuberance about 2.5 mm. high. At the base, anteriorly, is a small spine or spinose tubercle which develops into a strong spine in the mature forms; posteriorly, at the base, are three spinose tubercles. The plates of the depressed areas of the tegmen, between the large spines, are occupied by comparatively small plates just in back of the flexible integument which is the continuation of the interradial plates from the level of the secundaxil to the place where the arms of adjacent rays meet, at the first quartibrach in the young forms. The only mature specimen showing the tegmen belongs to another species, *T. devonicus* Springer, from the Hamilton of Clark county, Indiana. In this form the tegmen is highly arched and inflated, with deep interradial constrictions. The height is approximately that of the dorsal cup. The anal opening is situated high up in the tegmen. Protuberances rise above the high radial lobes. They are hollow and composed of small plates which form the sockets for the large spines. There are three large spines to a ray, two above each pair of arm bases and a larger one between them in the tegminal axil.

The *dorsal cup* measures 9 mm. to the top of the secundaxil in the smaller specimen; 14.6 mm. in the other. In both specimens the cup is subpentagonal in cross-section, as in the mature forms, due to the strong ridges that extend up the radial series and the flattened interradial areas. Of the three hexagonal basals the anterior, and largest, one shows a median suture, indicating that this plate is composed of two smaller pentagonal plates, not completely anchylosed. This feature is not shown in the medium-sized specimen here discussed nor in either of the mature forms, the cotypes. In the regular interradii the primary interbrachial is comparatively large and followed by two somewhat smaller plates in the second range; in the third and following ranges the plates follow in the series 3, 3 or 4, 3 or 4, 3 (at first tertibrach). There is a median line of anal plates in the posterior interradius extending up to the base of the anal tube. The proximal anal is of about the size of the radials and is followed by three in the second rank and then the series 5, 7, 7, 5, 3 (at arm base). The anal interradius shows a decided bulge above the primary anal. In the medium-sized specimen the plates of the anal interradius are not preserved above the third range.

The *arms* are not preserved far enough to show all the divisions. The anterior and left posterior rays preserve two divisions above the primaxil; the mature forms (the cotypes) show four divisions, giving five arms to each half ray. In the youngest specimen adjacent arms appear to meet at the first quartibrach, in the mature specimens at the quintaxil. The interbrachials between each half ray show the series 1, 2, 3. The flexible, triangular-shaped integument of small plates between the main arm trunks of adjacent rays measures 2 mm. in width at the base and 3 mm. in height in the smallest specimen; 3.5 mm. wide and about 5 mm. high in the medium-sized specimen. The point of flexure of this pliant integument seems to be about at the base of the secundaxils in the medium-sized specimen. This is not shown in the youngest specimen as the arms are not bent back.

The *ornamentation* in the youngest specimen, in addition to the spines on the tegmen and the ridges extending up the radial series consists in the interradial areas of ridges radiating from the center of each plate to all the edges. These ridges are particularly well-developed from the first to the fourth series of plates in the regular interradii. In the anal interradius they are well shown only on the primary anal and the plates of the second range. Obscure ridges may be seen on the plates of the third range. These radiating ridges are obscurely seen in the interradii of the medium-sized specimen, here discussed, and the smaller of the cotypes (*ref. cit.*, plate 26, fig. 8). The first interbrachial between the main arm divisions shows obscure radiating ridges in the youngest specimen.

All the changes from the youngest specimen, through the medium-sized specimen to the mature forms seen in the cotypes are only such changes as might be expected in the growth stages of the species.

II. NEW OBSERVATIONS ON OTHER HAMILTON CRINOIDS.

Through the courtesy of Mr. Irving G. Reimann, Curator of Geology in the Buffalo Museum of Science, it has been possible to study his recent collections of previously described species of Hamilton crinoids. Additional observations have been made upon the camerate species *Gilbertsocrinus multicalcaratus* Goldring, *Gennaeocrinus mourantae* Goldring, *Megistocrinus depressus* Hall, *Melocrinites powelli* (Goldring), *Dolatocrinus* cf. *bulbaceous* Miller and Gurley and *Cyttaro-*

crinus eriensis (Hall) and the inadunate species *Botryocrinus crassus* (Whiteaves) and *Poteriocrinites kopfi* (Goldring).

Gilbertsocrinus multicalcaratus. This species was first described in the Annals of the Carnegie Museum (vol. 24, p. 352, pl. 26, figs. 5, 6, 1935) and was based upon a specimen in which neither the arms nor the tegmen are preserved. The specimen in the Buffalo Museum, E13984, comes from the Moscow (Kashong) shale, Eleven Mile creek, Darien, New York. It is poorly preserved; but it shows part of one arm, a small portion of the tegmen with the bases of two interradial appendages, two large radial plates with long, strong spines and one interradial plate with no spine, so that there is no question as to identification. The tegmen is flat, composed of comparatively large plates, which apparently are papillose or have a small, central tubercle. The one arm is preserved for a length of 2½ cm. and is uniserial, with brachials wider than high and none of them showing a tendency toward wedge shape. The pinnules are long and slender, at least 11 mm. long and probably considerably longer, with long ossicles several times longer than wide. The arm is so preserved that nothing can be ascertained as to bifurcation. Of the species for which arms have been found *G. spinigerus* (Hall) has, through bifurcations, four arms to each ray (20 arms); *G. intersculptus* Goldring has usually six arms to the ray (30 arms), though a specimen with five arms in one ray is known; a specimen referred to *G. alpenensis* Ehlers apparently has four arms to the ray. In the last two species the arms are compactly biserial, in *spinigerus* uniserial.

Gennaeocrinus mourantae. A third specimen of this species (E13893, Buffalo Museum of Science) has come from the Ludlowville (Olentangy) shale, old dam on Ausable River, Arkona, Ontario. In this topotype the arms are preserved for a length of 35 mm. to 40 mm. A typical arm is 2 mm. wide near the base (thickest part) and 1.3 mm. wide near the limit of preservation. In the original description (Bul. Buffalo Soc. Nat. Sci., vol. 15, no. 3, p. 187, pl. 2, figs. 1-5, 1934) the arms were noted as six to the ray, the inner arm of each pair bifurcating once. In the specimen under consideration three rays show six arms, but seven are present in the right anterolateral ray and possibly seven in the left anterolateral ray (a break causing the uncertainty). In the posterior half of the right anterolateral ray the left (posterior) branch of the inner pair branches again a few millimeters above the first bifurcation,

giving four arms to this half ray. If the left anterolateral ray bears seven arms, as indicated, the right (posterior) half ray has both the inner and outer arm bifurcating once; the other half ray has three arms in the normal manner. Apparently there is some variability in the number of arms of this species.

Megistocrinus depressus. A comparatively young specimen (E13977, Buffalo Museum of Science) from the Moscow (Kashong) shale, Eleven Mile creek, Darien, New York, preserves a portion of the column, not described or figured hitherto for the species *depressus*. The column is similar to that of *Megistocrinus ontario* Hall as figured by the writer on plate 34, figure 9 of *Devonian Crinoids of New York* (N. Y. State Mus. Mem. 16, 1923). The proximal portion of the column is preserved for approximately 16 mm. It consists of nodals and internodals, the nodals much thickened and projecting in a striking manner, the diameter of the largest nodal being 6.3 mm. and that of the internodals 3.4 mm. The nodals are in four ranks or sizes in the portion preserved. Between two of the largest, or first rank, nodals occurs one of the second rank and between the latter and each of the first rank above and below occurs one of the third rank, which indicates the manner in which the column was lengthened.

The specimen here discussed is a crushed and partial cup showing two radii and two regular interradii. One radius shows four free arms, the other two, which is characteristic of the species in which the anterolateral rays bear two arms each and the others four. The ornamentation is delicate as in the young specimen figured on plate 33, figures 10, 11 of the memoir cited. At first glance the inclination would be to refer this specimen to *M. ontario*, because of the character of the ornamentation and the similarity in the structure of the column; but the cup is more globose than in that species and has the narrower interradii of *M. depressus*. The ornamentation in *depressus* is variable. A mature specimen in the Buffalo Museum of Science (E14117) from the Moscow (Kashong) shale, Bowen Brook, Erie county, New York, shows ornamentation similar to that of *M. ontario* and in another specimen (E16556) from the Ludlowville (upper Wanakah) shale, Cazenovia creek, Springbrook, New York, the plates of the tegmen are covered with a spider web-like ornamentation reminiscent of *M. ontario*, though in other respects the specimen has the characteristics of *M. depressus*.

Melocrinites powelli. In the *Devonian Crinoids of New York* the writer described and figured (*ref. cit.*, p. 142, pl. 15, figs. 7, 8) as *Melocrinus* sp. nov. a very characteristic arm trunk from the Hamilton (Moscow) shale, Kashong creek near Bellona, New York, and referred to it a considerable length of column from the same locality, since similar parts of column were associated with the arm. Later, in a collection loaned by Percy R. Powell of Niagara Falls, New York, was found a dorsal cup of a mature form to which was attached a column in all respects like the one figured in the memoir and a very small portion of one arm trunk, which seemed to indicate that the arm described as *Melocrinus* sp. nov. belonged to this species. This specimen from the Moscow shale, Bowen creek, Genesee county, was described as *Melocrinus powelli.* To these species was also referred the tegmen of another specimen from the same locality (Ann. Carnegie Mus., vol. 24, p. 355-358, pl. 25, figs. 3, 4, 1935).

The Buffalo Museum of Science collection contains a young specimen (E13889) from the Kashong shale of Bowen brook (or creek) which shows considerable portions of two arm trunks, the proximal portion of the column and the lower portion of the tegmen on the posterior side, establishing the correctness of the reference of the separate arm trunk and tegmen to *M. powelli.* The posterior interradius has been seen for the first time in this young specimen. It is comparatively broad and bulging, but unfortunately somewhat crushed. The median line of plates is preserved to the seventh. The primary interbrachial is slightly larger than the radials and is followed by three smaller plates in the second rank, apparently seven in the third, above which are many small plates merging into the small tegminal plates. The radial ridges are well shown on the plates of the posterior interradius, particularly those in the lower ranks. A specimen (E13975), probably more mature than the type, comes from the Moscow (Kashong) shale, Eleven Mile creek, Darien, New York. The crenulated edges of all the plates are well shown, though best displayed from the primibrachs on. The infrabasals have strong basal projections, the radial ridges are strong and the plates of the dorsal cup are thickened at the margins into flattened ridges which occur usually in three series, giving a nested appearance.

Dolatocrinus cf. *bulbaceus.* This species has not hitherto been reported from New York State, and no closer identification

than the above is justified by the preservation of the specimen from the Moscow (Kashong) shale, West Alden, New York, (E14619 in the Buffalo Museum of Science). This specimen fulfils the requirements of *D. bulbaceous* as described by Springer (U. S. Nat. Mus. Bul. 115, p. 42, 43, pl. 11, figs. 1-3, 1921) in ornamentation, character of the radials, as far as preserved (through second secudibrachs), and interradials. In one interradius it is not possible to tell whether the second plate is heptagonal and in another the second plate is followed by two plates in the third row, as noted and figured by Springer. The tegmen seems to have been composed entirely of a few large plates, two large, lozenge-shaped plates meeting the third row of interradials. The anal tube is central or nearly so. On both sides in each ray a small plate rests upon the second interradial and the first secundibrach, a feature apparently shown only by *D. bulbaceus*. The type figured by Miller and Gurley (Bul. Ill. State Mus. no. 4, p. 22, pl. 2, figs. 13-15, 1894) is referred to by Springer (*ref. cit.*, p. 43) as an abnormal specimen, incorrectly drawn. Springer describes this species as a wide ranging form and cites it as recorded only from the Hamilton limestone of Louisville, Kentucky, and vicinity and Thedford, Ontario (*Dolatocrinus subaculeatus* Whiteaves, a synonym).

Cyttarocrinus eriensis. The holotype and only known specimen of this species from its original description in 1862 (Hall: 15th Ann. Rept. N. Y. State Cab. Nat. Hist., p. 119, pl. 1, fig. 1) until 1935 is in the American Museum of Natural History, No. $\frac{5023}{1}$ (Hamilton group, Hamburg, Erie county, New York.) In a collection loaned for study in 1935 by Percy R. Powell of Niagara Falls, New York, was found a dorsal cup from the Ludlowville shale (Wanakah member: *Pleurodictyum* beds), Wanakah, New York. Recently the Buffalo Museum of Science has acquired a crushed dorsal cup (E13895) collected by Max J. Kopf of Lancaster, New York, from the Ludlowville shale, Windom, New York.

Botryocrinus cressus. This species described by Whiteaves in 1887 (Contr. Can. Pal. vol. 1, pt. 2 advance sheets, p. 95; 1889, pl. 12, fig. 2) was redescribed by Bather in 1906 (Ottawa Naturalist, vol. 20, no. 5, p. 101) from the holotype in the Museum of the Geological Survey of Canada, a specimen from the Hamilton, near Thedford, Ontario. Specimens were not

known from any other locality until the writer came across an incomplete dorsal cup in the collection of Percy R. Powell of Niagara Falls, New York, from the Ludlowville shale (Wanakah member, *Demissa* beds), Highland Acres, Erie county, New York. Bather (*ref. cit.*) notes slight traces of shagreen ornamentation on the posterior basal and anterior radial, but the surface of the holotype is not well-preserved. The writer, in the description of the Powell specimen (Ann. Carnegie Mus., vol. 24, p. 361, 1935) notes that shagreen ornamentation is very distinct on the infrabasal and basals (no radials preserved.) A third specimen (E16555 in the Buffalo Museum of Science), collected by F. W. Wattles of Buffalo from the Moscow (Kashong) shale, railroad cut east of Alden, New York, has come into the hands of the writer. This is a complete dorsal cup showing in two rays the first primibrachs, not known from the holotype, which are quadrangular and of equal height and width. Shagreen ornamentation is well-developed on all plates.

Poteriocrinites kopfi. In the collection of the Buffalo Museum of Science is a specimen (E15417) of *P. kopfi* from the Moscow (Kashong) shale near East Bethany, New York, which shows well the character of the ornamentation in maturity.

EXPLANATION OF PLATE I.

Figs. 1-3. *Thamnocrinus springeri* Goldring. 1, Posterior view of theca of youngest specimen, x3, showing bulge above primary anal. Sutures retouched. 2, Tegmen of the same, x3, showing well the lobate form, depressed interambulacral areas, pronounced ambulacral ridges marked by the stumps of large spines and the short, excentric anal tube Unretouched. 3, Anterior view of theca, x2, showing well developed radial ridges on plates of regular interradii. Sutures retouched.

Moscow shale, Livingston county, N. Y. Collection of Max J. Kopf, Lancaster, N. Y.

Fig. 4. *Gennaeocrinus mourantae* Goldring. Basal view with posterior interradius at top, x1, showing length of arms and character of bifurcations Unretouched.

Ludlowville (Olentangy) shale, Arkona, Ontario. Collection of Buffalo Museum of Science.

Fig 5 *Melocrinites powelli* (Goldring). Young specimen, x2; posterior interradius at right. Spines well shown on arm trunks. Unretouched.

Moscow (Kashong) shale, Bowen brook, Genesee co., N Y. Collection of Buffalo Museum of Science.

Fig. 6. *Poteriocrinites kopfi* (Goldring) Posterior view, x5, of specimen showing numerous papillae on all plates. Note appearance of raised rim at margins.

Moscow (Kashong) shale, near East Bethany, N. Y Collection of Buffalo Museum of Science.


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The surface of all the plates of the dorsal cup was described originally (Goldring, *ref. cit.*, pp. 362, 363, pl. 27, figs. 4-11) as "finely papillose, a character not always well-preserved." In this specimen the papillae have developed into tubercles strong enough to be apparent to the naked eye and giving a shagreen effect to the plates. In some places tubercles may be seen to coalesce and along the margins of some plates coarse tubercles are so close as to give the appearance of a raised rim.

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THE STRATIGRAPHY OF THE INDEPENDENCE SHALE OF IOWA.

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PART I.

ABSTRACT. Since its initial discovery and description by Calvin, the stratigraphic position of the Independence shale has been in dispute among authors generally. In this paper are summed up all available evidences seen in natural and artificial exposures and secured from deep and shallow well records. All concur in indicating that, normally, the Independence shale lies immediately below the Cedar Valley limestone and above the Wapsipinicon formation. As the Independence has a definitely lower Upper Devonian fauna, the relative age of the superjacent Devonian formations of Iowa is evident.

THE DEVONIAN SECTION OF IOWA.

THE Devonian beds of Iowa are mainly limestones with subordinate beds of shale and rare sandstone. As worked out at the present time, the columnar section of the formations and members recognized is as follows:

Formation	Members	Lithology
Sheffield	undivided	shale and sandstone
Lime Creek	Owen	limestone
	Cerro Gordo	shale
	Juniper Hill	shale
Shellrock	Nora	limestone
	Rock Grove	limestone
	Mason City	limestone
Cedar Valley	Coralville	limestone
	Rapid	limestone
	Solon	limestone
Independence	undivided	shale
Wapsipinicon	Davenport	limestone, lithographic
	Spring Grove	limestone, dolomitic
	Kenwood[1]	shale and limestone
	Otis	limestone, sublithographic
	Coggon	limestone, dolomitic

There are considerable differences of opinion among authors regarding the age of some of the formations. The Sheffield is

[1] The name Kenwood, as used by Norton, 1894, antedates the usage of the term by Butts for a Mississippian formation in 1915.

placed in the basal Mississippian by some and in the Upper Devonian by others.[2]

The Hackberry formation of Webster and authors includes the Cerro Gordo and Owen members of the Lime Creek but not the Juniper Hill shale. Hackberry and Lime Creek then are not equivalents. The column of Iowa Devonian formations ascribed by Cooper[3] to the present writer has the Hackberry formation intercalated between Shellrock and Sheffield. Hackberry as an Iowa formational term is not recognized by the Iowa Geological Survey and has never been used as equivalent to the Lime Creek by the present writer. The Lime Creek and Shellrock are generally recognized as Upper Devonian age.

The Cedar Valley is variously placed in the Middle and in the Upper Devonian. Since its age will be determined by the position of the Independence shale and, as its fauna is the subject of another paper, it need not be further considered here.

The Independence shale has a fauna which everyone recognizes is Upper Devonian. Its stratigraphic position, in dispute, is the subject of the present paper and is discussed fully in the following pages.

The Wapsipinicon because of its scant fauna cannot be definitely assigned to any age at present.

The State Quarry limestone is distinctly younger than the Cedar Valley but cannot at this time be unquestionably correlated with any known formation, nor can its position relative to the Lime Creek or the Shellrock be determined with the evidence now at hand.

HISTORY OF PREVIOUS INVESTIGATIONS.

The first mention of the Independence shale as far as known occurs in the Civilian, an Independence, Iowa, newspaper for March 12, 1857. A public well sunk a short way east of the river bank passed through twenty feet of limestone (Cedar Valley) and entered dark shale which contained carbonaceous matter resembling "cannel coal."

Sometime before 1877 shale and coal were discovered beneath the basal beds of a quarry in Cedar Valley limestone one mile east of Independence. A shaft in search of supposed coal deposits was sunk not far away. A depression indicating the

[2] Moore, R. C: 1935, Kans. Geol. Society, Ninth Annual Field Conf, p. 245, fig. 202.

Laudon, L. R.: 1935, idem., p. 246.

[3] Cooper, G. A.: 1942, Bull. Geol. Soc. Amer., vol. 53, p. 1737.

location of this pit is still visible with fossiliferous shale and carbonaceous clay about it.

This shale discovery was brought to the attention of Dr. Samuel Calvin of the State University of Iowa who studied the area and collected fossils in the material thrown out of the pit. His results were given in a paper read before the Iowa Academy of Science on June 23, 1876, and later published as a part of the Bulletin IV of the United States Geological and Geographical Survey of the Territories. In this article the shale was described and named and descriptions given of several new species of fossils.

In 1880 W. H. Norton published in the Cedar Rapids Republican, a newspaper for February 21, the section of the pit dug at Independence in search for coal. This section is given later in this paper.

In 1891 Calvin described in a preliminary report on the geology of Buchanan County, Iowa, the section at Independence and stated that the Independence shale occurred below the Cedar Valley limestone but above brecciated limestone. The following year he corrected his section, noting that the brecciated limestone was the same as the strata immediately above the shale. He adds "a few points have been found where the shales, by a little digging, may be seen beneath the breccia."[4]

Norton[5] placed the Independence shale below a brecciated unfossiliferous lithographic limestone to which he gave the name "Lower Davenport."

Norton noted the occurrence of fossiliferous shale in a railroad cut at Linn Junction, Iowa. This outcrop was rediscovered thirty years later by the present writer in the cut now long abandoned by the railroad. Norton also noted the recovery of a typical Independence fossil from blue shale 100 feet below the surface in a well drilled at Walker, Iowa. Norton states that in a well at Lafayette, Iowa, black shale and coal was found below four feet of soil and 80 feet of limestone (Cedar Valley). However, Norton[6] considered the shale to be below the Fayette breccia and correlated it with the unfossiliferous Kenwood shaly limestone and shale.

[4] Calvin, Samuel: 1891, Additional notes on the Devonian rocks of Buchanan Co, Iowa: Amer. Geol., vol. 8, p. 142.

———: 1892, idem, vol. 9, p. 345.

[5] Norton, W. H: 1894, Notes on the Lower Strata of the Devonian series of Iowa: Iowa Acad Sci Proc., vol 1, pt 4, pp 22-24.

[6] Norton, W. H.: 1895, Geology of Linn County· Iowa Geol Surv, vol. 4, p. 157.

Calvin,[7] discussing the geology of Buchanan County, noted several occurrences of the shale, listed the fauna, and stated that the shales were the lowest recognized member of the Devonian in the county with the "Fayette breccia" and the Cedar Valley limestone above. Parenthetically it may be interpolated here that the term "Fayette breccia" as used by Calvin included basal Cedar Valley beds and that in all cases where "Fayette breccia" lies above Independence shale, it is basal Cedar Valley and not the lithographic Davenport ("Lower Davenport of Norton").

In 1916-17, M. A. Stainbrook found several fossiliferous exposures of the Independence shale near Brandon, Iowa These were later investigated and reported on by A. O. Thomas[8] and W. H. Norton.[9] They concluded that the fossiliferous Independence shale lies somewhere below the Cedar Valley limestone and that its occurrence adjacent to Cedar Valley beds was due to the deformation and upthrusting of the plastic shale.

T. E. Savage[10] stated that he had visited the original pit and dump at Independence, Iowa, and suggested that the shale was a pocket of Lime Creek shale in a crevice in Cedar Valley limestone.

G. S. Dille[11] reported the occurrence of a black bituminous pyritiferous shale near Palo, Iowa. He suggested that it might be correlated with the Independence shale. The present writer has since verified that this outcrop of shale is definitely Independence by finding several of its characteristic brachiopods therein.

S. W. Stookey[12] reported the roadside exposure of shale and limestone in the Amana communities in Iowa County. Fossils were obtained by him and submitted to the present writer who definitely identified them as Independence and not Lime Creek. Doctor Stookey, however, concluded that the shale beds at

[7] Calvin, Samuel: 1898, Geology of Buchanan County: Iowa Geol. Surv, vol. 8, p 222.

[8] Thomas, A. O : 1920, The Independence Shale near Brandon, Iowa: Iowa Acad Sci Proc., vol 26, pp 485-491

[9] Norton, W. H · 1920, Wapsipinicon Breccias of Iowa: Iowa Geol. Surv, vol. 27, p. 388

[10] Savage, T. E : 1920, The Devonian Formations of Illinois: Amer. Jour. Sci., 4th series, vol. 49, p 180.

[11] Dille, G S.: 1924, Notes on the Occurrence of a Black Bituminous shale near Palo, Linn County, Iowa: Iowa Acad Sci., Proc, vol. 30, pp 441-443.

[12] Stookey, S. W : 1932, New Data on the Upper Devonian of Iowa: Iowa Acad Sci Proc., vol 39, pp. 183-191.

Amana were Lime Creek and again correlated the Independence shale with that terrane.

At this same time W. H. Norton sent the present writer some fossils found in drilling samples from a shale below forty feet of limestone at Shellsburg, Iowa. These fossils were recognized as typical Independence forms. Norton[13] published the log of this well in which the Independence shale is placed immediately below the Upper Davenport (basal Cedar Valley of Stainbrook).

S. W. Stookey[14] having learned of Norton's discovery of fossils in the Shellsburg well, reiterated the interpretation that the shale was the remnant of strata occurring in erosion channels, solution cavities and joints in the Cedar Valley limestone and therefore younger.

M. A. Stainbrook[15] summed up the current knowledge of the Iowa Devonian. He summarized the facts gained about the Independence shale after twenty years of study, discovery of some twenty new exposures, collection of hundreds of fossils from the shale and study of numerous well logs and samples. He separated the Independence shale from the Wapsipinicon as distinct from the Kenwood shale and placed it as indicated from all available evidence where Calvin had years before,—namely, below the Cedar Valley limestone and above the Davenport lithographic limestone.

E. H. Scobey[16] following a lithologic study of the Wapsipinicon placed the Independence shale above the Cedar Valley although it is apparent that he saw but few of the exposures of the shale. He stated that there was not room for the shale between the Cedar Valley and the Davenport although the formations are unconformable and elsewhere have sandstone between. Later[17] he stated his belief that the Independence shale is Lime Creek.

[13] Norton, W. H.: 1935, Deep Wells drilled in Iowa: Iowa Geol. Surv., vol. 36, p. 350

[14] Stookey, S. W.: 1933, Status of Devonian Beds at Middle Amana: Iowa Acad. Sci. Proc, vol. 40, p 133

[15] Stainbrook, M. A: 1935, Stratigraphy of the Devonian of the Upper Mississippi Valley: Kansas Geol. Soc. Guidebook, 9th Ann. Field Conf., p. 252.

[16] Scobey, E. H.: 1938, Sedimentary studies of the Wapsipinicon Formation of Iowa: unpublished thesis, State University of Iowa.

[17] Scobey, E H.: 1940, Sedimentary Studies of the Wapsipinicon Formation of Iowa: Jour. Sed. Petrol., vol. 10, no. 1, p. 41.

A. K. Miller[18] placed the Independence shale in the basal Upper Devonian.

S. W. Stookey[19] again stated that the Independence shale is post-Cedar Valley and residual on it. To M. A. Stainbrook is mistakenly attributed this statement,—"It now seems to me almost certain that the Independence shale and its fauna have been let down into the Cedar Valley limestone and to be far out of normal stratigraphic position." The present writer never made this statement and does not believe that it is in accord with the facts.

Stainbrook[20] stated that the Independence shale was Upper Devonian in age, distinct from the Lime Creek and present below the Cedar Valley limestone and above the Davenport beds.

Cooper[21] discusses the Independence shale, first giving the position of the present writer and secondly that of Warthin and himself, namely, that the shale is not in normal position. In addition he states that the Independence fills sinks and caverns, has a spotty occurrence and has a fauna of Nunda or High Point age. In his appended chart, Cooper places the Independence below Cedar Valley in the Middle Devonian and indicates that the fauna is Upper Devonian between the Juniper Hill and Cerro Gordo members of the Lime Creek stage.

Schuchert[22] in his columnar section places the Independence as a member of the Lime Creek beds between the Juniper Hill and the Cerro Gordo.

STRATIGRAPHIC POSITION OF THE INDEPENDENCE SHALE.

It is evident from the summary given above that there are several contrasting opinions regarding the position of the Independence shale in the Iowa Devonian column. By Norton the shale is regarded as a member of the Wapsipinicon formation occurring between the Otis limestone below and the litho-

[18] Miller, A. K: 1938, Devonian Ammonoids of America: Geol. Soc. Amer., Spec. Paper no. 14, p. 6.

[19] Stookey, S. W.: 1939, Significance of Carboniferous and Late Devonian Material within the Iowa Devonian· Iowa Acad. Sci. Proc., vol. 41, pp. 227-231.

[20] Stainbrook, M. A: 1940, Independence Shale in Iowa (abstract): Bull. Geol. Soc Amer., vol. 51, p. 1978.

[21] Cooper, G. A.: 1942, Correlation of the Devonian Sedimentary Formations of North America: Bull. Geol. Soc. Amer., vol. 53, p. 1766.

[22] Schuchert, Charles: 1943, Stratigraphy of the Eastern and Central United States, p 700

graphic brecciated Davenport limestone above. This correlation of the Independence with the Kenwood which does occur in company with the Spring Grove in this situation is considered by the present writer to be disproved by the[23] complete stratigraphic, faunal and lithologic differences between the two terranes. Scobey [24] also notes that the Kenwood is only 25 per cent insoluble while the Independence is a true shale and insoluble for the greater part. No fossil of the Independence and no Independence has been found lying on Otis. Unless evidence is discovered to the contrary, the Independence may be considered as entirely distinct from the Kenwood member of the Wapsipinicon.

In the second place the Independence shale by some geologists (Savage, Stookey, Cooper[25]) is considered to be out of normal position and to occur at or near the base of the Cedar Valley as portions of some younger formation filling caverns, crevices and erosion channels in the limestone. This post-Cedar Valley formation is said by several (Stookey, Scobey[26]) to be the Lime Creek shale because of the superficial resemblance of its fauna to that of the Independence. It is shown in a current paper by the present writer that the Independence and the Lime Creek faunas are quite distinct and not of the same age. The thesis that the Independence shale is simply Lime Creek shale out of place is not a tenable one.

Granting that this conclusion is true, is there any other formation later than the Cedar Valley which could have been the possible source for the shale supposedly out of place at the base of the Cedar Valley? Cooper and Schuchert[27] suggest that there was such a formation and that it was intercalated between the Cerro Gordo and Juniper Hill members of the Lime Creek Apparently they tacitly admit that the Lime Creek (Cerro Gordo member) could not be the source of the shale which Calvin designated as Independence. It is sufficient to

[23] Stainbrook, M. A: 1935, op. cit., p. 252.
[24] Scobey, E. H: 1940, op. cit., p. 41.
[25] Savage, T. E.: 1920, op. cit. pp. 179-180.
Stookey, S. W.: 1932, op. cit., 1932, p. 191.
Cooper, G. A.: 1942, op. cit., p. 1766
[26] Stookey, S W.: 1932, idem, p. 191.
Scobey, E. H.: 1940, idem, p. 41
[27] Cooper, G. A.: 1942, idem, p. 1787.
Schuchert, Charles: 1943, op. cit., p. 705.

state here that there is no field evidence of this hypothetical formation in that stratigraphic situation. The Cerro Gordo beds overlie the Juniper Hill beds conformably and grade into them with no perceptible break.

Lastly the Independence shale is considered by others (Calvin and Stainbrook) to occur in normal stratigraphic position below the Cedar Valley limestone and above the Davenport, the uppermost lithographic member of the Wapsipinicon. The present writer after a study of the shale in all of the known outcrops believes that this conclusion is the only one in accord with the facts thus disclosed. Evidences in support of this contention are developed along three main lines: that afforded by undisturbed exposures of the formation, that given by a study of deep and shallow well records and samples and that presented by faulted exposures of the shale.

NATURAL EXPOSURES.

The most important evidence for the determination of the position of the Independence shale is yielded by natural exposures where the strata are in normal stratigraphic position and but little disturbed. These exposures are few in number as would be expected as they are all west of the outcrop belt where exposures would normally occur. They are found only in the deep valleys of the major streams.

Near Independence, Iowa, along the right bank of the Wapsipinicon river south of town and one mile distant from the original discovery pit, Calvin[28] noted the presence of shale below the basal beds of the Cedar Valley limestone. Years later the present writer saw this shale as Calvin described it and secured typical Independence fossils from it. At the present time the outcrops are usually obscured either by vegetation and river deposits or covered by water, but are unquestionably below the basal Cedar Valley beds.

About a mile and a half northwest of Quasqueton in Buchanan county is an elongate hill some two miles long and adjacent to the Wapsipinicon river. Scattered outcroppings of limestone show that it is composed almost wholly of Cedar Valley with the beds dipping southward. Along both sides of the hill typical fossiliferous Independence shale occurs at sev-

[28] Calvin, S Geology of Buchanan County: Iowa Geol Surv. vol. 8, p 223

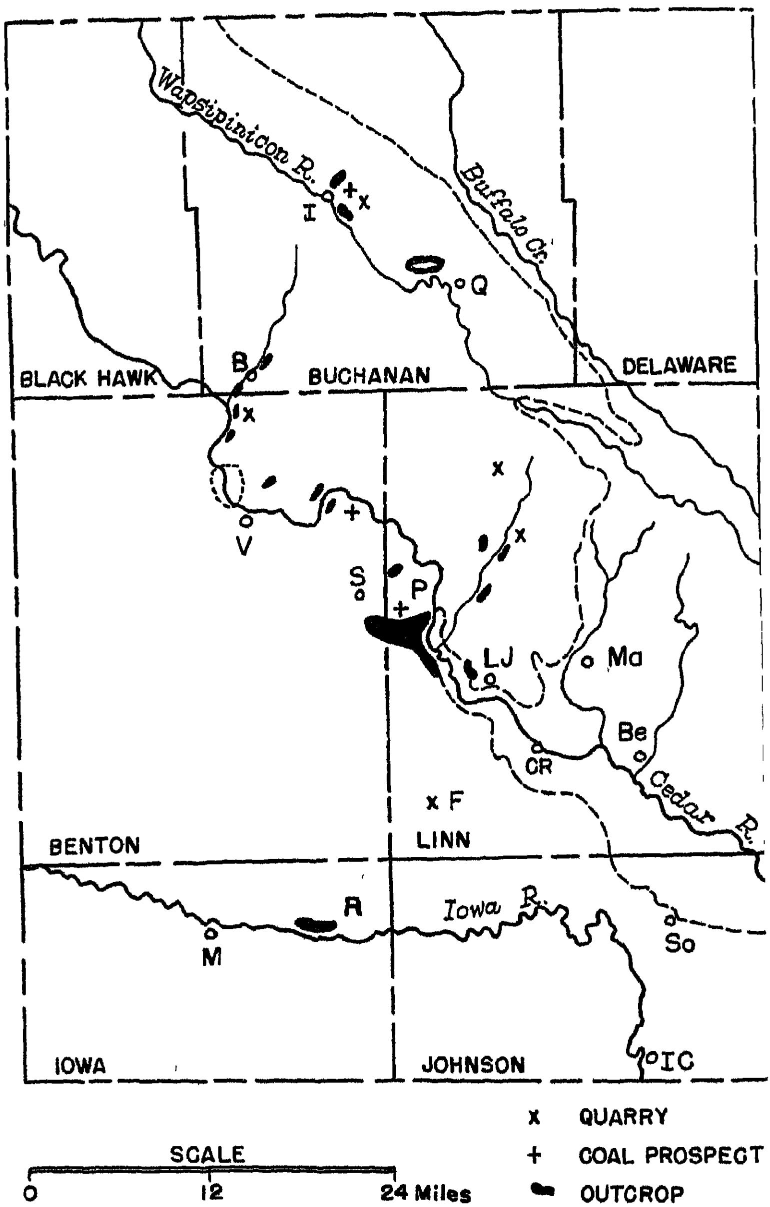

Fig. 1. Map of Benton, Buchanan, Linn and portions of adjacent counties, Iowa, showing local occurrences of the Independence shale. Outcrop areas are exaggerated. Key: A, Amana; B, Brandon; Be, Bertram; C.R., Cedar Rapids; F, Fairfax; I, Independence; I.C., Iowa City; L.J., Linn Junction; M, Marengo; Ma, Marion; P, Palo; Q, Quasqueton; S, Shellsburg; So, Solon; V, Vinton. The broken line is the approximate eastern border of the Cedar Valley limestone. The area at Amana is that of the Amana beds which are younger than Cedar Valley.

eral places beneath the basal layers of the Cedar Valley. The most illuminating exposure is seen on the west side of the north end of the hill where a freshet has recently (1940) uncovered the strata in a ravine in the bluff and has exposed the following section (see Fig. 2):

4. Pleistocene deposits.
3. 20 ft. limestone with numerous fossils· Cedar Valley.
2. 6 ft. blue-gray shale with fossils. Independence.
1. 2 ft. ledge of lithographic non-fossiliferous limestone· Davenport member of the Wapsipinicon.

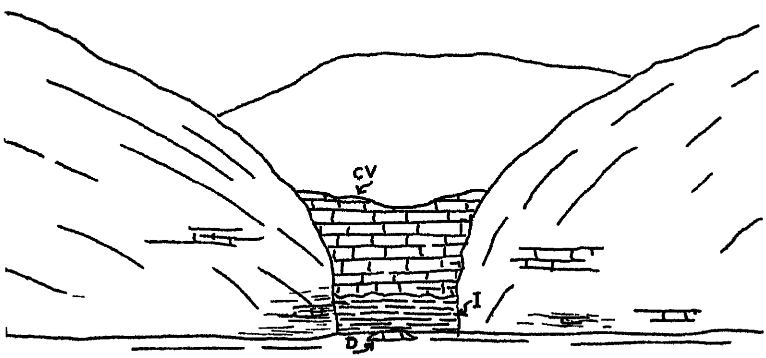

Fig. 2 Section revealed in ravine three miles northwest of Quasqueton, Iowa, showing 15-20 feet of basal Cedar Valley limestone overlying 5-6 feet of fossiliferous Independence shale. I, Independence shale; C.V., Cedar Valley limestone; D, block of Davenport limestone.

In none of the exposures around the hill is there a suggestion that the shale is in other than natural sequence and a continuous outcrop of several miles is indicated. At the south end of the hill the dip of the strata is sufficient to cause the shale to pass from view below the Cedar Valley limestone.

Another outcrop showing the shale in normal position is on East Otter Creek in section 8 of Monroe township of Linn county, Iowa. Here fossiliferous shale overlies typical brecciated Davenport limestone and underlies the fossiliferous Gyroceras beds which form the basal zone of the Cedar Valley.

On Little Bear Creek near Palo in the same county is another instructive exposure which has been described by Dille.[29] The shale was explored for coal and later as a possible source of cement materials. The shale apparently "was encountered in numerous borings along the valley" and thus appears to be

[29] Dille, G S · 1924, op cit., p 441

present over a considerable area up and down the stream. A shaft was sunk into a low terrace in the north side of the broad valley. This shaft penetrated sixteen feet of gray and dark carbonaceous shale with coal and nodules of pyrite. Typical Independence fossils occur in the debris thrown out of the pit. To the south an eighth of a mile distant the south wall of the valley rises precipitously some sixty feet. Scattered ledges of rock show that the major portion of the hill is underlain by Cedar Valley limestone. Along the foot of the hill for a distance of several hundred feet the basal beds of the Cedar Valley outcrop. Directly beneath these Cedar Valley strata is Independence shale with typical fossils. This shale is on the same level as the deposit explored in the terrace on the north side of the valley. The relations are shown in the accompanying

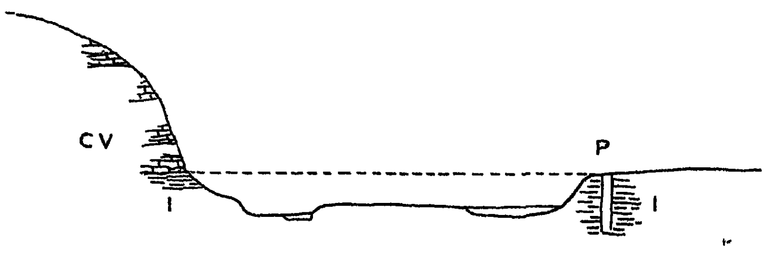

Fig 3 Diagrammatic section on Little Bear Creek north of Palo, Iowa The shale was penetrated for 16 feet by a coal prospect shaft and appears at the same level beneath Cedar Valley limestone about 40 rods to the southward. I, Independence shale C V., Cedar Valley limestone; P, coal prospect shaft.

diagram (Fig. 3). The extent of the shale in outcrop and as revealed by borings, its stratigraphic position and undisturbed nature precludes any hypothesis of the deposition of the shale in a cave below Cedar Valley limestone.

ARTIFICIAL EXPOSURES.

Further evidence of the stratigraphic position of the shale is that afforded by shafts and excavations. In that area of Iowa where Cedar Valley limestone forms the country rock, numerous reports of coal reached in wells and borings have been made. Several shafts[30] have been sunk in search of coal as in the instance at Independence where the shale was first brought

[30] Calvin, S.: 1878, U. S. Geol. and Geog. Surv., vol. 4, no. 3, p 726. 1898, op. cit, p. 251.

to light. The section in this shaft was published by Norton several years later (1880) and later[31] given as follows:

Fossiliferous Hamilton limestone	20 feet.
Black fissile bituminous shale	12 feet.
Gray fossiliferous shale	4 feet.
Hard gray rock with pyrite	2 feet.

In this section the uppermost bed is certainly the Cedar Valley limestone. The two beds of shale are Independence and the lowermost bed seems to be the Davenport. A pit several feet deep is still visible showing the situation of this shaft about ten feet beyond the north face of a quarry in Cedar Valley limestone. Typical Independence fossils and samples of the carbonaceous shale are still present about the pit. A dug well sunk about 1857 in the city of Independence passed through 20 feet of limestone and encountered shale with coal below.

About six miles north of Shellsburg in Benton county, Iowa, at the old ferry landing on the south bank of Cedar river is Barr's Bluff. This is formed by the beds of the lower portion of the Cedar Valley formation. Years ago a shaft was sunk here and according to Misters Carver and La Tourrene of Shellsburg, coal was actually taken from it at a depth of thirty feet.[32] A pit still shows the site of the shaft and comparison with the neighboring exposure of Cedar Valley limestone to the immediate west demonstrates that a depth of thirty feet would reach the bottom of that formation.

At Lafayette, Linn county, Iowa, in 1877, a miner's shaft[33] was sunk which passed through four feet of soil, 81 feet of limerock (Cedar Valley) and uncovered a coal seam one inch thick. A half mile northeast of Lafayette in the east valley of the creek valley a quarry has been opened in the basalmost beds of the Cedar Valley. In a sump pit at the south end of the quarry, and below the limestone the present writer recovered blue shale with typical Independence fossils. In a quarry one and a half miles south of Alice in the same county, in a recent quarry, shale was disclosed beneath Cedar Valley and above Davenport lithographic limestone.

At Fairfax in Linn county, one block north of the C. and NW. station, a quarry was opened several years ago as a source

[31] Norton, W. H.: 1920, op cit, p 309.

[32] Savage, T E · 1905, Geology of Benton County: Iowa Geological Survey, vol. 15, p. 199.

[33] Norton, W. H.· 1920, Wapsipinicon Breccias of Iowa· Iowa Geol. Surv, vol. 27, p 387.

of road material. The beds quarried are the basal beds of the Cedar Valley. At the south end a sump was made and blocks of blue-gray shale two feet thick and four feet long were brought up from below the Cedar Valley limestone. The shale was undisturbed and contained Independence fossils. The quarry has since been abandoned, partly because of the slight thickness of limestone available and because of the bogging effect of the shale below, when reached by the removal of the limestone.

On Little Bear creek near Palo, as disclosed by Dille,[34] a shaft 3½ by 4½ feet, was sunk into the Independence shale. The log in brief is:

3. 2½ ft. gravelly yellow clay: Pleistocene.
2. 16 ft. black, and blue shale, alternating, with coal and pyrite seams: Independence shale.
1. Concretionary limestone and limestone: Wapsipinicon.

Since shale identified as Independence by its fossils is present beneath the Cedar Valley several hundred yards to the southward, the limestone beneath the shale could not be Cedar Valley.

The natural and artificial exposures of the Independence shale demonstrate that it occurs in natural sequence above the Davenport limestone and below the Cedar Valley consistently. The shale in several instances, as at Quasqueton and at Palo, is of such an extent as to preclude the interpretation of the shale as a cave deposit. Also on fresh exposure, the shale is seen to be normally bedded in horizontal layers in no way comparable to that to be expected in a cave or crevice filling washed down through 150 feet of limestone. That Cedar Valley and Shellrock fossils or blocks of limestones from these formations would escape being incorporated during the process of cave filling is nearly inconceivable. Yet in the undisturbed Independence in these exposures, the shale is uncontaminated by either Cedar Valley or Shellrock fossils and debris. It seems unescapable that the Independence shale was deposited prior to these two formations.

SHALLOW WELL RECORDS.

Numerous shallow well records attest to the presence of shale beneath the Cedar Valley limestone over a wide area. While

[34] Dille, G. S.: 1924, op. cit.

these records are not based on samples which can now be studied, they must be conceded some considerable degree of

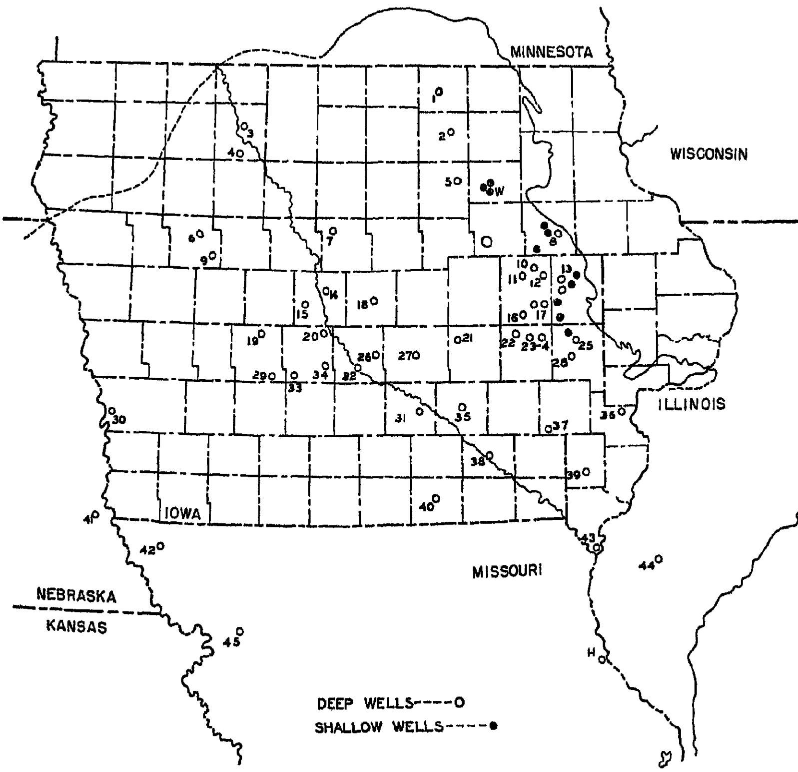

Fig 4 Map of Iowa and portions of adjacent States, showing the occurrence of Independence shale in deep and shallow wells, Key: 1, Osage; 2, Charles City; 3, Emmetsburg; 4, Mallard; 5, Clarksville; 6, Sac City; 7, Webster City; 8, Quasqueton; 9, Auburn; 10, Vinton; 11, Garrison; 12, Shellsburg; 13, Center Point; 14, Boone; 15, Nevada; 16, Ogden, 17, Newhall and Atkins; 18, Watkins; 19, Bayard; 20, Woodward; 21, Grinnell; 22, Marengo; 23, South Amana; 24, Homestead; 25, North Liberty; 26, Mitchellville; 27, Newton; 28, Oakdale; 29, Stuart; 30, Dexter; 31, Waukee. 32, Des Moines; 33, Council Bluffs; 34, Flagler; 35, Oskaloosa; 36, Letts. 37, Brighton; 38, Ottumwa; 39, Mount Pleasant; 40, Centerville; 41, Nebraska City, Neb.; 42, Tarkio, Mo.; 43, Keokuk, Iowa; 44, Colmar-Plymouth area, Ill.; 45, St. Joseph, Mo.; H, outcrop of sandstone south of Hannibal, Mo.; W, Waverly, Iowa The solid line is the approximate eastern limit of the Cedar Valley limestone; the broken line is its approximate subsurface boundary.

accuracy. An experienced well driller has little difficulty in distinguishing between shale and limestone as they are encountered by the drill in shallow borings. These records are extracted from the various reports on the geology of the county concerned. In all cases the interpretation of the formation and identification of the same is by the present writer.

In the northern part of the Cedar Valley outcrop is the Osage City well in Mitchell county, Iowa. The log is as follows:

Depth	*Material*	*Formation and Age*
0–20	drift	Pleistocene
		Devonian
20–180	limestone	Cedar Valley
180–200	gumbo shale	Independence
200–660	limestone	Wapsipinicon and Silurian

In Bremer county several wells show shale below Cedar Valley as is evident in the logs of these wells.

William Coon well, one mile north of Waverly:

Depth	*Material*	*Formation and Age*
0–75	drift	Pleistocene
		Devonian
75–120	limestone	Cedar Valley
120–122	shale	Independence
122–136	limestone	Wapsipinicon

E. Bennett well, three miles north of Waverly:

Depth	*Material*	*Formation and Age*
0–10	yellow drift	Pleistocene
10–70	blue clay	Pleistocene
		Devonian
70–114	limestone	Cedar Valley
114–124	gray shale	Independence
124–138	limestone	Wapsipinicon

Wm. Colton well, three miles northwest of Waverly:

Depth	*Material*	*Formation and Age*
0–20	drift	Pleistocene
		Devonian
20–50	limestone	Cedar Valley
50–65	black shale	Independence
65–92	limestone	Wapsipinicon

In Buchanan county where the Independence shale was first discovered and named, several well logs show shale below the Cedar Valley limestone.

In Jefferson township in the northeast one-fourth of section 2, a well gave this record:

Depth	*Material*	*Formation and Age*
0–100	drift	Pleistocene
		Devonian
100–120	limestone	Cedar Valley
ends in shale		

This well is four miles north of the outcrops of Independence shale in the valley of Lime Creek described by Norton[35] and Thoms.[36]

A well in Washington township has this record:

Depth	*Material*	*Formation and Age*
0–72	limestone	Cedar Valley
ends in "soapstone"		Independence

This well is one mile east of the discovery pit at Independence. In the same section another well has this log:

Depth	*Material*	*Formation and Age*
0–20	drift	Pleistocene
		Devonian
20–156	limestone	Cedar Valley
156–196	gritless clay	Independence
flinty rock at base		Davenport

In Linn county there are numerous shallow wells which show shale below the Cedar Valley. A few records are given here. One mile south of Lafayette is the J. Maier well. It showed:

Depth	*Material*	*Formation and Age*
0–3	soil	
3–74	limestone	Cedar Valley
74–89	soapstone	Independence
89–92	sandstone	Independence

It should be noted that well drillers usually designate shale as "soapstone." This well is also within a mile of the locality where fossiliferous Independence shale can be seen in place

[35] Norton, W H.: 1920, Iowa Geol. Jour., vol. 27, p 388.
[36] Thomas, A O.· 1920, Iowa Acad Sci. Proc, vol. 26, p 485.

below Cedar Valley and above Davenport limestone on East Otter creek. The F. P. Kratzer well is one and a half miles northwest of Lafayette:

Depth	*Material*	*Formation and Age*
0–120	limestone	Cedar Valley
120–124	shale	Independence

This well is within a mile of the place where shale was collected from beneath Cedar Valley. The O. Gilchrist well, one-half mile south of Paris, shows this section:

Depth	*Material*	*Formation and Age*
0–9	drift	Pleistocene
9–47	limestone	Cedar Valley
blue shale and a little coal at bottom		Independence

The W. D. Bucklin well is three miles west of Paris and has this log:

Depth	*Material*	*Formation and Age*
0–20	soil and clay	Pleistocene
20–140	limestone	Cedar Valley
dark shale at bottom		Independence

The C. Rake well is a half mile south of Palo and two miles south of the outcrop of Independence on Little Bear creek. It shows:

Depth	*Material*	*Formation and Age*
0–10	soil	
10–33	sand	Pleistocene
33–63	yellow and blue clay	Pleistocene
63–83	limestone	Cedar Valley
83–98	shale	Independence

The T. C. Martin well is two miles south of Fairfax where shale was uncovered below the bottom layers of Cedar Valley limestone in a recent quarry.

Depth	*Material*	*Formation and Age*
0–40	yellow clay	Pleistocene
40–90	hard fossiliferous limestone	Cedar Valley
soapstone and sandstone at bottom		Independence

In Johnson county the Mrs. Morris well three miles east and two miles north of North Liberty shows this section:

Depth	*Material*	*Formation and Age*
0–40	yellow clay	
40–42	sand	
42–92	blue clay	Pleistocene
92–94	sand	Pleistocene
		Devonian
94–204	blue limestone	Cedar Valley
204–212	shale	Independence
212–226	white porous rock	Davenport

It is readily admitted that these shallow well records may be questionable evidence, in the opinion of some geologists, regarding the stratigraphic position of the Independence shale. Yet these records may be of considerable importance, especially when reinforced by the facts yielded by the artificial and natural exposures in the near vicinities of the wells.

(*To be continued.*)

PROLACERTA AND THE PROTOROSAURIAN REPTILES.

CHARLES L. CAMP.

PART II.

COMPARISONS.

Prolacerta differs from modern lizards and agrees with the Upper Permian eosuchians *Youngina, Youngopsis* and *Youngoides* in the following characters:

1. Quadratojugal present
2. Jugal with a long quadrate process
3. Dentition thecodont (pleuro-thecodont)
4. Pterygoids broadened and extending forward to the vomers
5. Postfrontal separate from postorbital and primitive in position and shape
6. Interparietal present (?)
7. Squamosal short and wide, postfrontosquamosal arch short and stout
8. Basioccipital short and narrow
9. Nasals extensive

Prolacerta also has the following presumably primitive characters not found in modern lizards and not yet recorded in eosuchians:

10. Exoccipitals and paroccipitals separate
11. Odontoid separate
12. All cervical vertebrae with ribs
13. Epipterygoid stout and with a quadrate process
14. Articular and prearticular separate (this point is doubtful)

Prolacerta shares with certain primitive geckonid lizards the following:

15. Vertebrae amphicoelous, notochordal
16. Cervical intercentra small and crescentic
17. All median elements of the skull roof paired
18. Stapes perforated at base (?)

Prolacerta agrees with most lizards and differs from *Youngoides* in having:

19. Streptostylic quadrate
20. Symphysis of lower jaws ligamentous (?)
21. Basipterygoid process fused with basisphenoid
22. Postorbital arch narrow

Prolacerta appears to differ from most lizards and *Youngoides* in:

23. Absence of a supratemporal bone (fused with squamosal ?)
24. Absence (or extreme reduction) of the pineal foramen
25. Presence of a reduced kinetic quadratojugal
26. Posterior process of jugal nearly reaching the quadrate

Prolacerta agrees with *Sphenodon* and *Youngoides* and differs from lizards in having:

1. A quadratojugal
4. Pterygoids which reach forward to articulate with the vomers
8. Basioccipital short and narrow

Prolacerta agrees with *Sphenodon* and differs from lizards in the following:

27. A longitudinal ridge of teeth on the palatine bones
28. Squamosal squarish with four subequal processes
29. Absence of a separate supratemporal bone (?)
30. Presence of a paired proatlas
31. Orbits large
32. Dorsal temporal fenestra nearly circular
33. Epipterygoid stout and expanded at base

Prolacerta agrees with the type specimen of *Protorosaurus speneri* in:

34. All characters of the vertebrae and cervical ribs so far as shown
35. The pleuro-thecodont insertion of the teeth (cf. Seeley 1888)
36. The general shape of the skull and the arrangement of the skull elements: elongate nasals, narrow maxillaries, shape of the frontals, and prefrontals, narrow elongate vomers with teeth, large orbit with bony sclera, slender lower jaws with splint like splenial reaching far forward, angular and surangular not extending to tip of retroarticular process

Prolacerta may differ from the type of *Protorosaurus speneri* in some of the following characters:

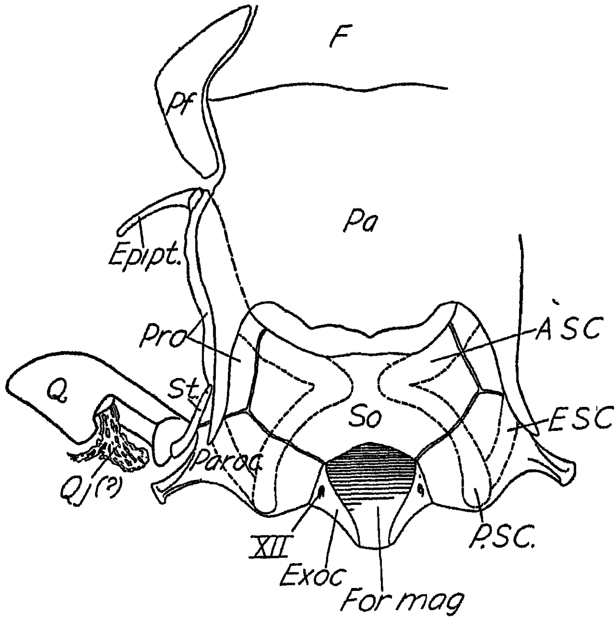

Fig. 7. Dorsal view of part of skull of *Coleonyx variegatus*, U. C. Mus. Vert. Zool. no. 26980, cleared specimen, adult, x 10. The "quadratojugal" (Qj?) occupies a recess in the quadrate similar to that of *Prolacerta* A.S C. = Anterior semicircular canal, E.S.C. = External semicircular canal, P.S C. = Posterior semicircular canal; St. = Supratemporal ("Tabulare" of lizards). Nerve XII has a single internal opening and two external foramina.

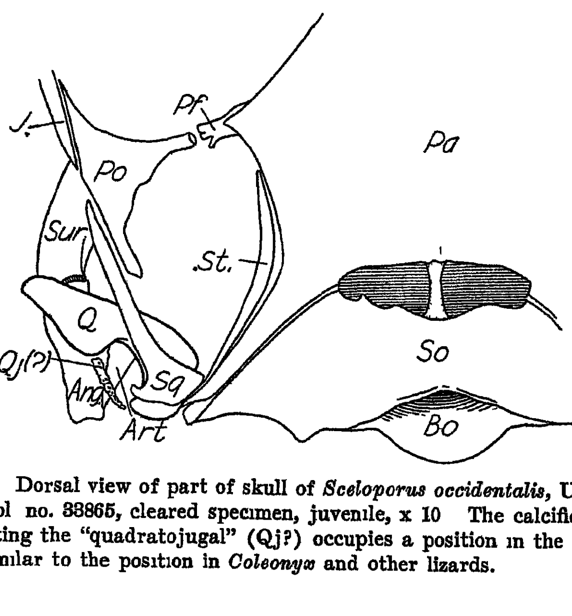

Fig. 8 Dorsal view of part of skull of *Sceloporus occidentalis*, U C. Mus. Vert Zool no. 33865, cleared specimen, juvenile, x 10 The calcified tissue representing the "quadratojugal" (Qj?) occupies a position in the digastric fascia similar to the position in *Coleonyx* and other lizards.

37. Lack of a pineal foramen (?); small or absent (?) in *Protorosaurus*
38. Lack of a crest on the mid-parietal line; broken away in *Protorosaurus* (?)
39. Lack of a fenestra in front of the lacrimal; doubtfully present in *Protorosaurus*
40. Skull slightly smaller in *Prolacerta*
41. Cervical vertebrae about half the length of those in most of the known specimens of "*Protorosaurus*"

Some of these characters may now be discussed:

1. A quadratojugal has been questionably noted in skinks by Kingman (1932). Cleared specimens at hand of *Coleonyx*, *Sceloporus* and *Phrynosoma* show a small calcified "element" resting upon a mid-lateral facet of the quadrate (Text Figs. 7, 8) in about the same position as the quadratojugal of *Prolacerta*. In the more advanced lizards, *Gerrhonotus* and *Cnemidophorus* this element joins the upper head of the quadrate and lies at the origin of the quadrate slip of the digastric muscle. In all these lizards the element in question is a thin, calcified mass of somewhat indefinite form and boundaries, lying in the digastric fascia. It may well be a vestigial quadratojugal, for the similarity of its relation to the quadrate in ascalabotid lizards appears to be more than a coincidence.

2. The jugal has a short posterior process in the Cretaceous lizards *Polyglyphanodon* (Gilmore 1942) and *Macrocephalosaurus* (Gilmore 1943). The only recent lizard in which I have seen such a process is the xantusiid *Lepidophyma*, where the process is also short.

3. Thecodont or pleuro-thecodont teeth are present only in the embryos of modern lizards. The Cretaceous *Chamops* and the mosasaurs retain them. The alveoli in *Prolacerta* are deeper on the buccal than on the lingual side of the jaws and the old teeth are fused to the margins of the alveoli.

4. The extent and shape of the pterygoids in *Prolacerta* resemble *Youngoides* and *Sphenodon* more closely than the lizards. In most reptiles, including *Sphenodon* and the lizards, a flange is developed along the juncture of the pterygoids and ectopterygoids, to guide the lower jaws into exact occlusion. This flange seems to be very weakly developed in *Prolacerta* as well as in *Youngoides*.

The pterygoids of *Iguana*, according to Lakjer (1927) and Olson (1936), meet the vomers. Olson says this union is con-

cealed in the adult by ventral overgrowths of the median wings of the palatines. The only *Iguana* skull immediately available to me shows a dorsal overlap of the palatines upon the pterygoids and the pterygoids are widely separated from the vomers.

Lakjer (1927) announces a "separate" element which he has named "hemipterygoid." This is described and figured as extending from the tip of the true pterygoid to the vomer along the inner margin of the palatine, in an embryo of *Iguana tuberculatus*. Lakjer also finds a so-called hemipterygoid in a young *Anolis cristatellus* and other forms. I have at hand cleared specimens of embryo *Phrynosoma* and young *Sceloporus* Here the pterygoids are widely separated from the vomers and the median parts of the palatines are not separate from the outer. The only evidence of an "hemipterygoid" is a slight longitudinal slit extending a short distance into the palatines.

Olson's figure of *Youngoides* shows no teeth on the vomers, but there is an extensive anterior tooth bearing process of the palatine. These teeth correspond in position to the teeth on the ridges of the vomers in *Prolacerta* so it may be that Dr. Olson has not correctly placed the sutures between the palatines and the vomers. With this exception the palatal resemblances bring *Prolacerta* closer to *Youngoides* than to any other reptile in which the palate is well known.

The palate of *Prolacerta* will also bear close comparison with *Sphenodon*. The elongate, laterally placed internal nares, the meeting of the wide vomers along the midline, the anterior extension of pterygoids, the peculiar shape of the palatine, the course of the sutural contact of the palatine and vomer, and the presence of longitudinal, tooth bearing ridges on the palatines and vomers, are similar in *Sphenodon* and *Prolacerta*. In fact, the resemblances in the palate alone would indicate closer relationship to *Stenaulorhynchus* and *Sphenodon* than to the lizards. The nature of the union of pterygoid and quadrate, the presence of a small pterygo-palatine fenestra (not found elsewhere among reptiles), the shape of the ectopterygoids, the narrow interpterygoid space, the small basioccipital, the shape of the squamosal, the large orbit and the circular shape of the supratemporal fenestra are further resemblances to *Sphenodon*.

Lakjer's (1927) studies on the shape and structure of the internal choanae of lizards are of interest. From comparison of palatal structures of various reptiles he would derive the

lizards from the rhynchocephalians and these in turn from cotylosaurs. He divides the lizards into: I *Palaeochoanatae* (Agamidae, Iguanidae, Helodermatidae, Anguidae, Geckonidae, Pygopodidae and Chamaeleontidae) in which the choanae and palatal bones are of a simpler "more primitive" type, more similar to *Sphenodon*, than are the: II *Neochoanatae* comprising the skinks, teiids, zonurids, lacertids, gerrhosaurids, varanids and amphisbaenids. By these criteria the palate and choanae of *Prolacerta* appear to be similar to *Sphenodon*; and more similar to agamids and iguanids than to other lizards.

5. Postfrontals in lizards are often larger than in *Prolacerta*, and this occurs secondarily among the Scincidae. The primitive diapsid position, shown in *Prolacerta*, is modified in recent lizards. Primitive relations are most nearly preserved in *Polyglyphanodon* and *Lepidophyma* where the parietals are narrow anteriorly as in *Prolacerta*. Owing to the anterior expansion of the parietals in modern lizards, the postfrontal acquires a concavity along its inner margin. This is foreshadowed in the Upper Jurassic *Ardeosaurus* which Broili (1938) believes to be related to the Xantusiidae.

6. An "interparietal" is described by Kingman (1932) in recent skinks. He figures this element as a nodule lying in or above the tissue connecting the mid-dorsal border of the supraoccipital with the parietals.

7. If previous observations on eosuchians are correct, the squamosal of *Prolacerta* may represent the fused supratemporal (=tabulare of Broom) and the squamosal of *Youngina*, *Youngoides* and *Youngopsis*. This fusion may indicate that *Prolacerta* is not directly in the line of ancestry of the lizards. But such fusions may not be significant.

8. A short, narrow basioccipital occurs in *Youngoides* and *Sphenodon* as well as in *Prolacerta*. The condition in *Prolacerta* strongly suggests that of *Youngoides* and the tubera are weak in both.

9. The great extent of the nasals is another important point of resemblance between the Permian eosuchians and *Prolacerta*. These bones are never so well developed in lizards, even in *Ameiva*, mosasaurs, and others with an elongate antorbital region.

Characters 15-18 are found in the geckos, among modern lizards. All the skull elements are paired in *Youngina*, *Youngopsis* and *Youngoides*, and in some modern geckos. The stapes is perforate in the geckos *Pachydactylus*, *Hemidactylus* and *Terentola*; *Coleonyx* (Fig. 9) has a large fenestra. These are the only lizards in which this primitive character is known to occur.

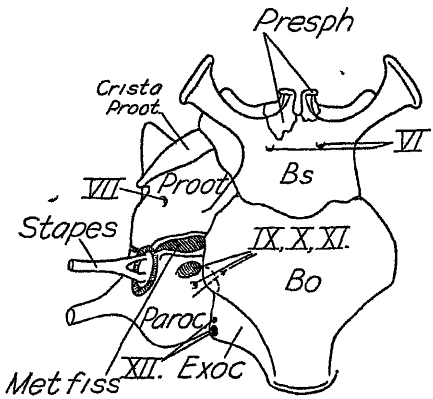

Fig. 9. Ventral view of part of skull of *Coleonyx variegatus*, Mus Vert. Zool. no. 26980, cleared specimen, adult, x 10 The stapes has a larger fenestra than in other known geckos. The metotic fissure (Met. fiss.) remains open. Nerves IX, X and XI have three foramina, the anterior also contains the perilymphatic sac. There is no parasphenoid. The paired presphenoid (Presph.) is separated by suture from the basisphenoid.

19 and 20. The lack of a direct articulation between the jugal and the quadrate, and the loose articulation of the quadrate with the squamal and quadrotojugal in *Prolacerta* makes it apparent that the skull was streptostylic, but not exactly as in lizards. The ligamentary symphysis of the lower jaws and the long digastric process of the angular is further evidence of streptostyly. In the face of so many obvious resemblances to *Youngina* and *Youngopsis* one might well hesitate to apply the criterion of streptostyly so strictly as to exclude *Prolacerta* from the eosuchians. *Prolacerta* is the earliest known streptostylic reptile and illustrates the way in which complete streptostyly probably arose, with the quadratojugal itself involved in the kinetism.

24. The pineal foramen is so variable in lizards (cf. Camp 1923, p. 394) that its apparent absence in *Prolacerta* may not be significant.

25. The quadratojugal was apparently movable along with the quadrate but in a slightly different direction. With a fore and aft movement of the foot of the quadrate, the quadratojugal would have moved dorsally and ventrally; at the same time its lower end would swing fore and aft in a short arc where it is loosely attached to the lateral margin of the quadrate.

Prolacerta seems to illustrate an early stage of streptostyly in which the initiation of movement in the quadrate has accompanied an equivalent movement in the reduced quadratojugal.

26. The slender posterior process of the jugal, which approaches but does not join the quadrate and quadratojugal seems to be another character intermediate between eosuchians and lizards. A similar posterior process of the jugal is also found in *Thalattosaurus* and the general similarity of the temporal region in *Thalattosaurus* and the eosuchians seems to indicate relationship between these groups.

27-33. The similarities between *Prolacerta* and the rhynchocephalians serve to emphasize their relationships and support the view (Broom 1922; and Huene 1938b) that the rhynchocephalians as well as the lizards are derived from Permian eosuchians, (see also points 1, 4, 8, 15-18, and 23).

Comparison with Tangasaurus.—*Prolacerta* seems to resemble *Tangasaurus* (Haughton 1924, 1929; Huene 1926b) in its amphicoelous, notochordal vertebrae, presence of cervical intercentra, unkeeled atlantal intercentrum, small basioccipital with tubera, basisphenoid with divergent posterior crests and prominent basipterygoid process, slender, elongate parasphenoidal rostrum, interpterygoid vacuity, at least one long row of large teeth on pterygoid, slender lower jaws with elongate retroarticular process, and stout curved first ceratobranchials.

The vertebrae in *Tangasaurus* are smaller and shorter, the neck is much shorter, the basioccipital tubera are more prominent, and the ceratobranchials are larger.

What remains of the dorsal skull roof in *Tangasaurus* is sufficiently like *Prolacerta* to be interesting. The frontals are narrow, the parietals are broader and form a squarish plate bounding a circular, closed temporal fenestra. The specimens preserved in the Paris Museum are figured by Piveteau (1926, Pl. IX, Figs. 1 and 2).

My own sketches of these specimens are shown in Text Figs. 10 and 11. The impression in Text Fig. 10 is probably the ventral surface of the skull roof. The skull of *Tangasaurus* is, of course, imperfectly known.

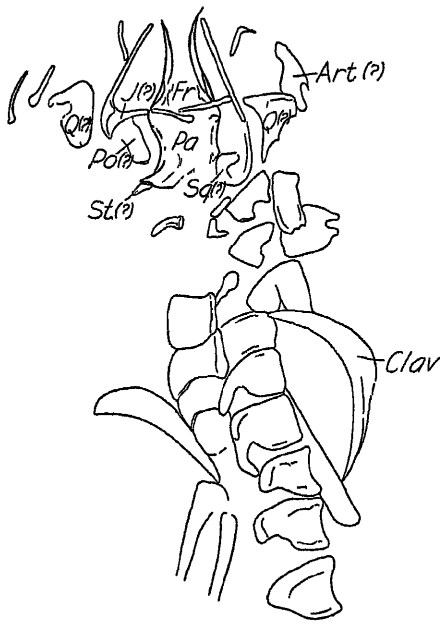

Fig 10. Ventral view (?) of skull roof of *Tangasaurus menelli,* from a plaster impression in the Museum d'Histoire Naturelle, Paris, x 1, (cf Piveteau 1926, pl. IX, fig. 2).

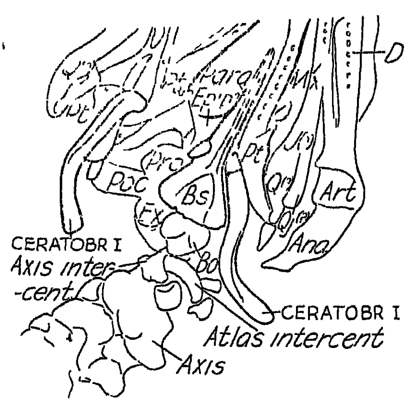

Fig. 11. Palatal view of part of skull of *Tangasaurus menelli,* from plaster impression, xl, (cf. Piveteau 1926, pl. IX, fig. 1).

34-41. *Comparison with Protorosaurus.*—The cervical regions of *Protorosaurus speneri* (Meyer 1856, Pl. 1, Fig. 1: Seeley 1888; and Huene 1926a) and *Prolacerta* will bear scrutiny. The cervical vertebrae are nearly identical and the cervical ribs as well, except that von Meyer has described the ribs of *Protorosaurus* as single headed. The division between the cervical rib heads in *Prolacerta* is weak and such a division may have been undetected in *Protorosaurus*. *Gracilisaurus* (Weigelt 1930), an apparently related genus, has bicipital ribs.

The centra are biconcave, elongate, and compressed below in *Protorosaurus* and *Prolacerta* and they both show ventral, arched muscle scars. The axis is shorter than the next three centra, and the fourth and fifth centra are the largest in each genus. The neural arches are nearly as long as the centra, especially on the axis, and their heights are less than the diameters of their centra. The neural arches decrease in length toward the rear. The zygapophyses are large, elongate, and those on the fifth vertebra are the longest. The diapophyses are small and occur at the extreme anterior margin of each centrum.

The post-axis intercentra are very small. Ribs occur on all the cervicals. The anterior ribs are extremely long and needle-like, and those behind become slightly expanded below the tuberculum.

The skull of the type of *Protorosaurus speneri* is best described by Seeley (1888). Its outlines indicate a long, low muzzle, slender jaws, and posterior orbit—large in *Gracilisaurus* and provided with sclerotic plates in both genera. The general outlines and proportions are similar to *Prolacerta*. There are many points of striking similarity, so there can be little question as to the close relationship of *Protorosaurus* and *Prolacerta*.

The teeth are sharp, single pointed, and slightly recurved in both reptiles. The adult teeth are fused to the margins of their sockets with more of the tooth base exposed lingually than buccally. The vomers bear teeth in both forms. The shape of the visible skull elements is much the same, the lower jaws are similar.

There is a possibility of further comparison between *Protorosaurus* and the skeletal parts shown in eosuchians.

In *Youngina* Broom (1922, 1924) has found a slender tibia and a tarsus somewhat similar to *Protorosaurus* in the disposi-

tion of the elements. There is, however, a fifth tarsale in *Youngina*, not apparent in *Protorosaurus*. The humerus of *Youngina* is also similar in shape. But there was an entepicondylar foramen in *Youngina* and *Palaeagama* (Broom 1926) not shown in von Meyer's figures of *Protorosaurus*. According to Peyer (1937) there are no humeral foramina in *Macrocnemus* and *Tanystropheus* which Peyer regards as related to *Protorosaurus*.

Weigelt (1930) refers to the entepicondylar foramen found by Etzold in *Protorosaurus*. He also calls attention to the *Sphenodon*-like shoulder girdle of his *Gracilisaurus*. In *Gracilisaurus* the cervical vertebrae and ribs are like those of *Protorosaurus*. The frontal bones are deeply sculptured, and the coracoid is single.

Prolacerta then closely resembles *Protorosaurus* and *Gracilisaurus* in the characters available for comparison, and these genera should be placed in the same general group. This could be expressed by mergence of the Protorosauridae with the "Eosuchia." Peyer (1937) and Huene (1938a) have already noted resemblances between some of these forms and Welles (1943) indicates the rather wide separation between *Protorosaurus* and *Araeoscelis*. Welles also has suggested placing *Protorosaurus* in the Eosuchia.

It would seem preferable to substitute Huxley's name *Protorosauria* for Broom's Eosuchia. Eosuchia was proposed later; furthermore the original genus *Eosuchus* is a crocodilian. "Eosauria" might be suggested but *Eosaurus* has turned out to be an amphibian.

SYSTEMATIC POSITION.

A. *Prolacerta* retains the following primitive reptilian characters:

Median elements of skull roof all separated by suture, brain case largely membranous, external nares anterior and paired, epipterygoid with a quadrate process, quadratojugal present, vertebrae notochordal, intercentra present, ribs on all cervical vertebrae, ribs bicipital, no cranial osteoderms.

B. The upper and lower temporal fenestrae of *Prolacerta* place it in the subclass Diapsida, although the jugal-quadratojugal arch is incomplete.

C. The skull, dental and vertebral characters of *Prolacerta* relate it most closely to *Protorosaurus*.

D. *Prolacerta* agrees with *Youngina*, and *Youngopsis* (Broom 1936, 1937, Olson and Broom 1937) in the arrangement of the elements of the skull roof and jaws. The palate is similar to *Youngopsis* and the posterior palatal elements resemble those of *Tangasaurus*. These may now be placed in the superorder Protorosauria (=Eosuchia).

E. *Prolacerta* possesses a streptostylic quadrate and in this respect agrees with the Squamata, and is probably ancestral to the lizards, in a general way.

F. The Squamata must then be regarded as diapsids rather than parapsids, despite their lack of a lower temporal arch.

G. *Prolacerta* resembles *Sphenodon* and the rhynchosaurians in the shape of the squamosal, the fusion or loss of the supra-temporal, the forward extension of the pterygoids and in other features. This would justify derivation of the Rhynchocephalia as well as the Squamata from the Protorosauria.

H. *Prolacerta* seems possibly to lie near the point of divergence of the Rhynchocephalia from the Protorosauria. Its concert of characters seems to place it in the Protorosauria (=Eosuchia), and within the family Protorosauridae. It cannot be directly ancestral to the rhynchocephs because of the break in the lower temporal arch and the freeing of the quadrate.

I. The Thalattosauria have a slender posterior jugal process which probably did not reach the quadrate or quadratojugal. The structure of the two temporal arches and the position of the supratemporal bone may indicate derivation from the early Protorosauria.

J. *Araeoscelis* could be regarded as an example of an early Permian ancestor of the later "Parapsida" and the Diapsida. Resemblances to *Protorosaurus*, as well as to the Sauropterygia, appear to be present. The position of the ichthyosaurs is extremely doubtful.

K. Parrington (1935) has assigned *Prolacerta* to the "Theocodontia." This evidently follows Watson's and Smith-Woodward's use of that term in the last edition of Zittel, where the Eosuchia are placed in Theocodontia together with the Pelycosimia, Parasuchia, and Pseudosuchia. Owen (1860) includes the following "types" in his "Order VII, Thecodontia": *Thecodontosaurus* and *Palaeosaurus* from the Upper Triassic near

Bristol, *Cladyodon* of Warwickshire "with which, probably the Belodon of the Keuper Sandstone of Wirtemberg is generically synonymous," and *Bathygnathus* Leidy "which is probably a member of the present order which seems to be a forerunner of the next Order VIII Dinosauria."

So, Owen evidently intended his Thecodontia to include the archosaurian Pseudosuchia+Phytosauria (= Huxley's Parasuchia). If the term Theocodontia is to be retained it may be better not to include therein the Protorosauria (=Broom's "Eosuchia"). The Archosauria may then be conveniently retained as a group equivalent in rank to the Lepidosauria.

L. The earliest and most primitive known archosaurs appear to be the lower Triassic genera *Proterosuchus* and *Chasmatosaurus*. *Proterosuchus* is imperfectly known and it is possible that the two belong to the same genus. Both have a similar dentigerous pattern on the palate. The teeth are fused to the alveoli and have been described as "acrodont." It might be desirable to restrict the term acrodont to those types, such as rhynchocephalians and Agamidae, in which there is a higher state of fusion accompanied by a loss of tooth replacement in the adult. In Proterosuchidae the replacement teeth appear to be successional. All told, the insertion is of course not strictly thecodont and appears to be of the same type to be seen in *Prolacerta* and *Protorosaurus*.

The resemblances between the Proterosuchidae and *Prolacerta* and *Youngina* also include the presence of a short row of teeth on the transverse process of the pterygoid; similar relations between the vomers, the palatines and the pterygoids; similarly shaped pterygoids; narrow interpteryoid space; and elongate, rod-like parasphenoidal rostrum.

The skull of *Chasmatosaurus* differs from the lepidosaurs in having an antorbital fenestra as well as a phytosaur-like bony case around the forebrain. Laterosphenoids and orbitosphenoids are presumably present. There is a small interparietal bone in *Chasmatosaurus* but the tabular has not been recognized.

Huene originally regarded *Erythrosuchus* as the chief example of his new order Pelycosimia. Later this group was reduced to the rank of a superfamily, with the invalid name "Pelycosimioidea," to include all the known Pseudosuchia. For the present it might be preferable to separate the Pseudosuchia into at least two main groups: (1) the Aëtosauroidea to include *Euparkeria* and the armored stagonolepids, and (2) the

Proterosuchoidea (new name) to include the Erythrosuchidae. The Proterosuchidae appear to have been derived from the Protorosauria, theoretically from an early form such as *Youngina*, in which the lower temporal arch and quadrate are quite intact.

RELATIONSHIPS OF PROTOROSAURIA.

The phylogeny of the Protorosauria might be expressed as in the accompanying diagram (Text Fig. 12).

A suggested classification based on this phylogeny would be·

Class Reptilia.
- Subclass Anapsida.
  - Order Cotylosauria.
  - Order Testudinata.
- Subclass Synapsida.
  - Order Pelycosauria.
  - Order Therapsida.
- Subclass Parapsida.
  - Infraclass Araeoscelidia (possibly including the Trilophosauridae).
  - Infraclass Synaptosauria (doubtful relationships).
  - Infraclass Ichthyopterygia (doubtful position).
- Subclass Diapsida.
  - Two or more temporal fenestrae (lost in Squamata).
  - Infraclass Lepidosauria, Haeckel 1868 (=Tocosauria, Haeckel 1870, partim).
    - Primitively with two temporal fenestrae, no antorbital vacuity, and a supratemporal bone; tabulare absent; laterosphenoids reduced or absent; pineal foramen usually present.
    - Superorder Protorosauria, Huxley 1871 (=Eosuchia+Trachelosauria, and Protorosauria of Williston, partim). Quadrate usually fixed; usually with a supratemporal bone, a quadratojugal.
      - Order Prolacertiformes (=Eosuchia, s.s., Broom 1914, Haughton 1929, Huene 1926b Protorosauridae;= Prolacertilia, partim, Huene 1940).
        - Nares terminal, a lower temporal arch. Includes: Protorosauridae, Saurosternidae (=Younginidae), Tangasauridae.
      - Order Trachelosauria (Broili and Fischer 1917; Peyer 1937).
        - Tanystrophaeidae.
        - Nares dorsal; apparently no lower temporal arch.
      - Order Thalattosauria (position uncertain).
        - Limbs in the form of paddles, palate narrow, teeth acrodont.

Order Acrosauria (position doubtful, cf. Broili 1926).
Pleurosauridae.
Superorder Rhynchocephalia.
Quadrate fixed; a quadratojugal; no separate supratemporal bone.

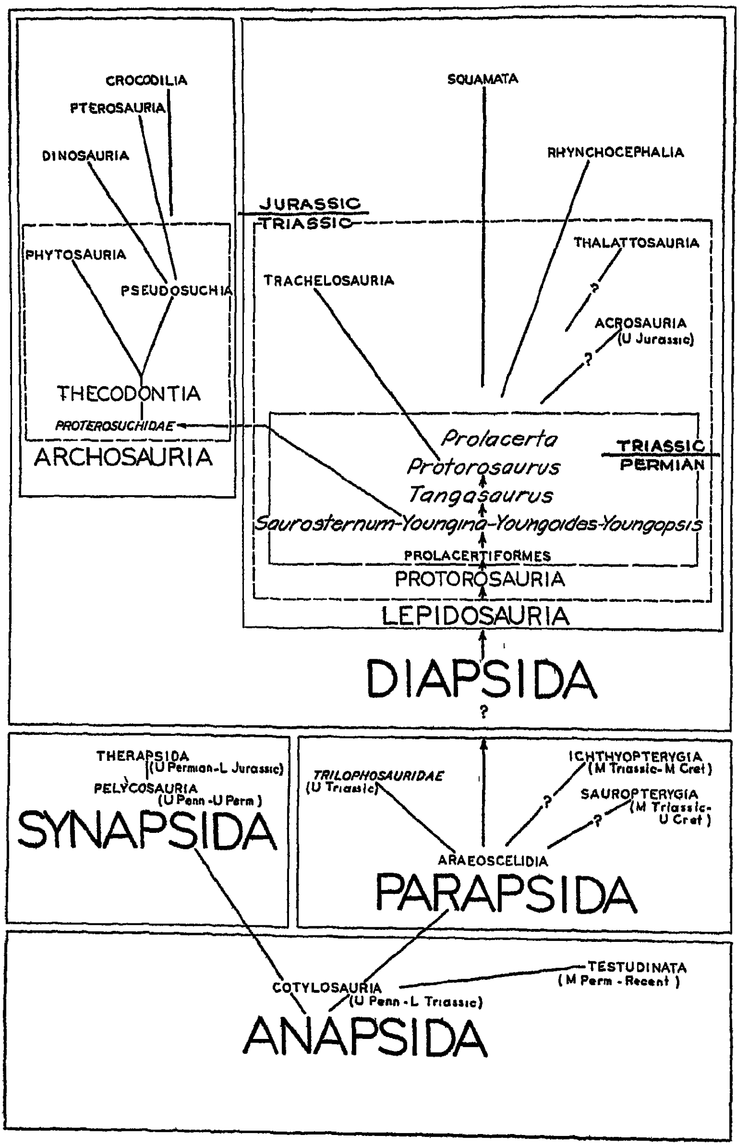

Fig. 12. Phylogeny and relationships of the Protorosauria.

Superorder Squamata.

Streptostylic quadrate; no ossified quadratojugal, supratemporal commonly present.

Infraclass Archosauria.

Primitively with two temporal fenestrae and an antorbital vacuity; supratemporal absent; tabulare (or supratemporal?) present in Phytosauria; laterosphenoids extensive; pineal foramen usually absent.

Superorder Thecodontia.

Order Pseudosuchia.

Superfamily Aetosauroidea.

Superfamily Proterosuchoidea.

Order Phytosauria.

Superorder Crocodilia.

Superorder Dinosauria.

Superorder Pterosauria.

AGE RELATIONS AND DISTRIBUTION.

The *Lystrosaurus* zone in the Karroo Series of South Africa has usually been considered as Lower Triassic in age. Elements of the fauna of this zone are widespread (Huene 1940a). *Lystrosaurus* and *Chasmatosaurus* occur together in Central Asia (Sinkiang) as well as in South Africa. Dr. Philipp Yuan, who collected the Asiatic material, has told me of a small, undescribed skull which was being studied by Dr. Ting-pong Koh. This specimen was taken to Munich and is mentioned by Huene as "gen. et sp. nov. Prolacertiliorum," indicating its resemblances to *Prolacerta.*

A combination of three "South African" elements in the Lower Triassic or Upper Permian of Central Asia would be noteworthy. An extreme western occurrence of *Lystrosaurus,* is at Orenburg province, in the southern Urals, 45 km. southeast of the town of Orenburg on the Donguz River in beds of "continental Lower Triassic," (Efremov 1938). Forms similar to *Chasmatosaurus* are reported in beds farther west in Russia (Huene 1940b). *Lystrosaurus* has also been somewhat doubtfully identified from India.

Absence of the *Lystrosaurus* fauna from Western Europe makes it probable that a hiatus, presumably the Uralian seaway, traversed European Russia from north to south and prevented the land faunas from mingling during this time. Some land or shallow water connections between Africa and Central Asia were evidently maintained across the Tethys.

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A SLAB OF FOSSIL TURTLES FROM EOCENE OF WYOMING, WITH NOTES ON THE GENUS ECHMATEMYS.

CHARLES W. GILMORE.

ABSTRACT. A slab containing fifteen turtle specimens prepared for exhibition in the United States National Museum is described. The article is concluded with a discussion of the variable structures in the carapace of the genus *Echmatemys*.

A UNIQUE exhibit added to the collection of fossil vertebrates in the United States National Museum is in the form of a block of matrix containing fifteen turtle shells *in situ*. This block was quarried from a deposit where the shells outcropped for thirty or more feet along the hillside, and extended inward for an undetermined distance, thus indicating the final resting place of several hundred of these lowly reptiles. The closely placed shells are all lying right side up in life-like position forming a thin layer from four to six inches in thickness. Of the twenty individuals collected in and around this one block, all but one, *Chisternon*, pertain to the genus *Echmatemys*.

This deposit was found by the 1930 Smithsonian Paleontological Expedition to the Bridger Basin in southwestern Wyoming, but nothing was done with it at that time. In 1941, however, in the belief that a slab showing the shells in place would make an interesting exhibition piece, Dr. C. L. Gazin, in charge of the expedition of that year, was instructed to visit the locality and if feasible to collect a block of suitable proportions. This was done and a slab 42 x 66 inches, weighing more than 1200 pounds, was secured. These shells have been skillfully worked out in relief by Chief Preparator Norman H. Boss, care having been observed not to disturb their original relationships, as shown in Plate 1. The rock was of such a nature that it could not be dressed to a condition suitable for exhibition purposes so its surface has been entirely replaced by artificial matrix cast from the original and colored to closely simulate it. At one corner of the block is an artificial section of the bank that shows two of the specimens partly excavated. It is thought this visual conception will better

explain to the visitor how all were originally embedded in the ground.

The quarry is located in the B horizon of the Bridger formation in the badlands on Levett Creek and immediately north of the Mountain View-Lone Tree road where it rises to cross the escarpment leading to the drainage of Cottonwood Creek.

The specimens are in a matrix of greenish gray tuff that Mr. E. P. Henderson, after a study of thin sections, reports on as follows: "The rock in which the turtles were found consists largely of volcanic debris and clay pellets. It contains many minerals common to volcanic ash, e.g. quartz, plagiclase, feldspar, biotite, greenhornblende and some devitrified glass. Most likely it is transported volcanic material. It may be that this rock represents an ash fall on a muddy basin or flood plain where clay pellets existed prior to an ash shower. The case is not clear cut either way and I can see nothing in the section to throw light on how the turtles could have been killed or covered."

The volcanic nature of the matrix certainly allows the suggestion that the turtles may have originally met their death as the result of an ash shower. If such an explanation is accepted, however, it calls for their subsequent disinterment and transportation to their present resting place. That the assemblage of such a large number of turtle specimens in this one spot does not represent a primary deposition after death is clearly indicated by the lack of articulated limbs and feet and the total absence of skulls, cervical, and caudal vertebrae. Likewise the missing carapace ends of a few specimens were absent from the surrounding matrix thus showing they were not broken on the spot. Curious enough the plastra of all are in good preservation, even those in which the carapace has suffered considerable damage.

The fact that all of the shells are lying in natural orientation is also difficult of explanation, unless it be that the arched carapaces may have trapped sufficient air to cause them to float right side up.

In 1908 when Dr. O. P. Hay[1] made a study of all available *Echmatemys* specimens, he called attention to the difficulty of characterizing species of the genus, and pointed out at some

[1] Hay, O P: 1908, Fossil Turtles of North America, Carnegie Institution of Washington, Pub 75.

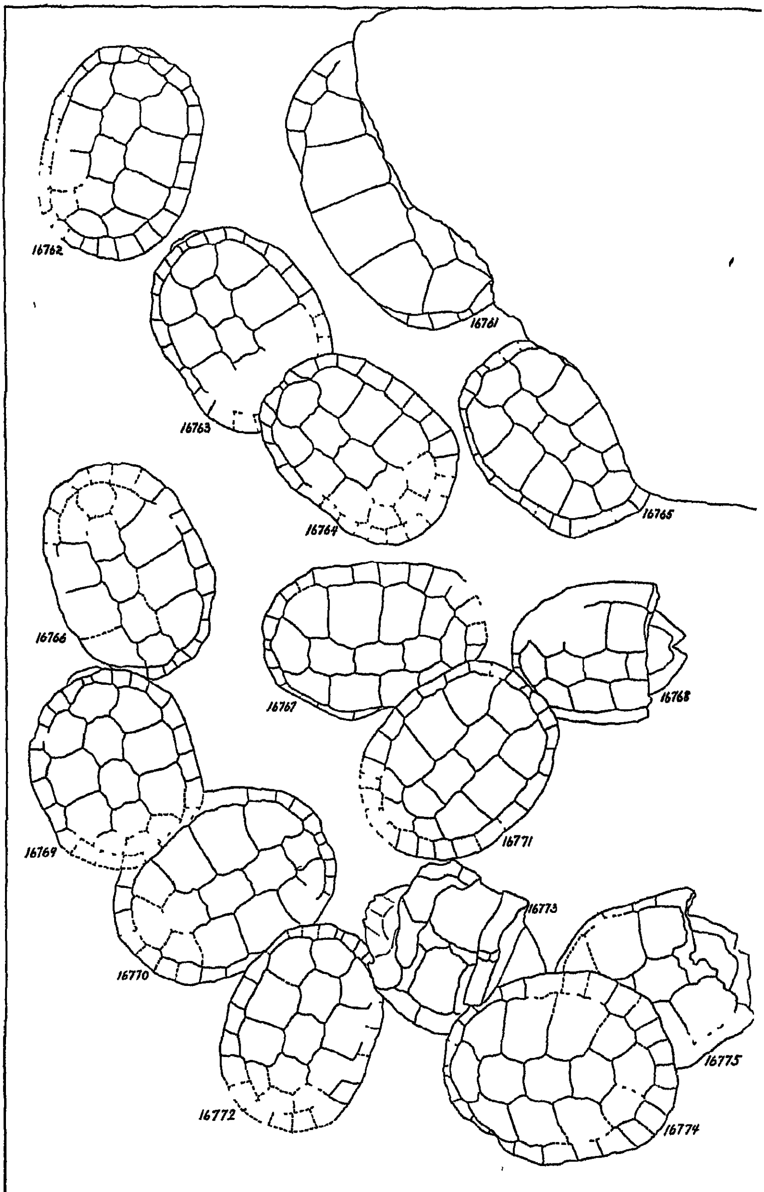

Fig. 1 Carapaces of *Echmatemys*, showing outlines of dermal scutes. No. 16761 U S N M. *E. haydeni* (Leidy); Nos. 16762 to 16775 U.S.N.M *E. wyomingensis* About 1/10 natural size.

PLATE 1

Slab of *Echmatemys* specimens Nos 16761 to 16775, U S. National Museum, shown as they lay in the ground Viewed from above About 1/10 natural size

length the inconstant nature of the structures used for specific differentiation. These observations are abundantly verified by the specimens now before me, even though they are from a common geological horizon, and presumably consist of individuals from a restricted area.

Fifteen specimens in the block, see Text Fig. 1, four others collected adjacent to it, and four specimens now in the Carnegie Museum, Pittsburgh, Pennsylvania collected from this same deposit by Dr. J. LeRoy Kay, can all be certainly identified as belonging to the genus *Echmatemys*. After long and critical comparison it was finally concluded that of the twenty-three specimens twenty-two are to be referred to *Echmatemys wyomingensis* and one (No. 16761, U.S N.M.) to *E. haydeni*.

Of the 18 specimens forming the U. S. National Museum series, 9 are complete enough to furnish measurements of the carapace. The longest measures 350 mm., the shortest 292 mm; their average length is 313 mm., average width 226 mm. These proportions are well within the range of measurements given by Hay for representatives of this species.

The vertebrals show considerable variation both in size and form. Of 17 specimens available for comparison, 10 may be grouped as having vertebrals with parallel sides; 7 as being bracketed; 13 have the second and third vertebrals subequal in length; 3 have the second shorter than the third. The first vertebral is usually widely expanded on the anterior end, but as clearly shown in Text Fig. 1, Nos. 16766 and 16770 have the first vertebral contracted at this end. As a rule the sulci are moderately impressed, but there are at least two individuals that have them deeply impressed. The nuchal scute is preserved on 9 individuals, 4 of which have the length equal to the width, the width slightly exceeds the length in the remaining five. The average length of this scute is 12.1 mm., average width is 13.2 mm.

In the few specimens in which the sutures are visible, the neurals are consistently hexagonal. There is some variation in their proportions, but not more than would be expected of individuals within the species. All of the shells have been flattened by pressure which in most instances has affected their symmetry, and has probably widened the carapace greater than in life.

In outline the carapaces are subovate, somewhat contracted in front of the forelegs. In most of the specimens the anterior ends are truncate, with or without slight emargination above the neck. Specimen No. 16772 differs from the others in having a more narrowed and pointed end. Taken all in all, however, the outlines of the shells are fairly constant in form, see Fig. 1. The shell surfaces are smooth, and with the exception of Nos. 16771 and 16774 are free from median ridges. The two exceptions show them only on the downward slope of the back.

For obvious reasons it has not been possible to contrast the plastra of their scutes. Regarding this portion of the *Echmatemys* carapace Hay observes, "Little aid in the differentiation of the species has been derived from the proportions of the plastral scutes." Likewise the buttresses are unavailable for study although much relied upon in the past study of the species of this genus.

At the time of writing his Fossil Turtles of North America, Hay recognized twelve species of *Echmatemys* as occurring in the Bridger formation. Arranged chronologically these were as follows:

	DATE
E wyomingensis (Leidy))	1869
E. haydeni (Leidy)	1870
E. stevensoniana (Leidy)	1870
E. latilabiata (Cope)	1872
E. septaria (Cope)	1873
E shaughnessiana (Cope)	1882
E arethusa Hay	1908
E cynae Hay	1908
E ocyrrhoe Hay	1908
E. aegle Hay	1908
E. naomi Hay	1908
E. pusilla Hay	1908

In the hope of finding evidence that some of the twelve recognized species from the Bridger were confined to certain horizons of the formation, a canvass was made, not only of the National Museum collections, but of all other sources of information, with rather indifferent results.

In addition to the series of *Echmatemys* specimens discussed in the preceding pages, the U. S. National Museum collections contain the remains of seventeen other individuals of this genus, four of which are original types. All of these have been collected from various localities in the Bridger Basin. Most of

the new materials are well preserved specimens, and although they can be confidently identified as to genus, their assignment to species is often made with reservations. Of these thirteen specimens two were identified as pertaining to *E. wyomingensis* (Leidy), two to *E. septaria* (Cope), three to *E. shaughnessiana* (Cope), two to *E. haydeni* (Leidy), one to *E. aegle* Hay, three to *Echmatemys* species.

It was determined that most of the known *Echmatemys* specimens were collected from the B horizon of the Bridger. Only one, *E. septaria*, appears to be confined to the upper part of the Bridger, in either C or D horizons. One specimen of *E. haydeni* was found in C horizon, but five other specimens including the type are reported from the B level.

In all probability, too many species of this genus have been named, but more specimens must be assembled before it is clear as to which of these could or should be eliminated. Using the same criteria as used in the past, I would be fully justified in establishing at least one new species from the present assemblage, but until more is learned of the range of variation in the genus, to do so would accomplish no useful purpose and would only add to an already confused situation.

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Washington, D C.

DISCUSSION.

THE STROMATOLITE GYMNOSOLEN NOT A SALINITY INDEX.[1]

In an earlier number of the AMERICAN JOURNAL OF SCIENCE, in a review of the literature on stromatolites (1), it was pointed out that those clearly of the gymnosolen type previously had been recorded only from known non-marine strata or from beds thought to be otherwise unfossiliferous. On the basis of the published record it was then stated that, if one doubtful instance could be excluded, "one could generalize to say that where a stratum contains 'gymnosolen' the chances are in favor of it being non-marine and the burden of proof is on the dissenter from this conclusion" (2). The conclusion proffered was that "although stromatolites of the gymnosolen type may suggest a fresh water habitat, they can be only contributory evidence and other criteria must be sought" (3).

Shortly after publication of this review a letter from Dr. Curt Teichert informed me of the existence of a gymnosolen in probable marine strata in Australia. Subsequently I have observed undoubted gymnosolen in marine Upper Cambrian strata (cherts of the Copper Ridge dolomite) of the southern Appalachian region and in marine Lower Ordovician limestones (especially the unit known as the Cool Creek limestone) of the Wichita and Arbuckle Mountains in Oklahoma. More recently W. F. Whittard and Stanley Smith(4) have recorded the occurrence of gymnosolen in marine middle Silurian (Wenlock) limestone.

From the evidence now at hand it is clear that gymnosolen by itself offers no clue as to whether the strata containing it were deposited in fresh or saline waters.

Earlier conclusions regarding the correlative value of stromatolites(5) have been substantiated in the field by the observed reliability of gymnosolen as indicative of the Upper Cambrian Copper Ridge strata of certain structural belts in northeast Alabama and northwest Georgia as contrasted with its complete unreliability in regional correlation.

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(1) Cloud, P. E, Jr: 1942, Notes on stromatolites, Amer Jour. Sci., Vol. 240, pp 363-379

(2) Idem., p. 372.

(3) Idem, p. 373.

(4) Whittard, W. F, and Smith, Stanley· 1944, Geol. Mag, Vol. 81, no. 2, pp. 71-72, Pl. 3.

(5) Cloud, P E., Jr.· idem., p 369

PRESTON E. CLOUD, JR.

[1] Published by permission of the Director, Geological Survey, United States Department of the Interior.

GEOLOGICAL SURVEY,
U. S. DEPARTMENT OF THE INTERIOR.

SCIENTIFIC INTELLIGENCE

Chemistry.

Vegetable Fats and Oils. Their Chemistry, Production and Utilization for Edible, Medicinal and Technical Purposes; by George S. Jamieson. Second Edition. American Chemical Society, pp. 508. Monograph Series, No. 58. New York, 1943 (Reinhold Pub. Corp., $6.75).—In the second edition of this very useful book the subject matter has been arranged along the lines of the first edition. The wealth of material which has come forth since the first appearance of the book has been reviewed and evaluated, and the information brought up to date. Workers in the field of fats will appreciate the new directions for the determination of standard values, in particular the thiocyanogen and the diene number. A twenty page appendix to the book contains many useful data in a tabulated form. Like its predecessor, this book belongs to the library of everyone who has more than a passing interest in the chemistry of fats and oils. WERNER BERGMANN.

Luminescence of Liquids and Solids and Its Practical Applications; by P. Pringsheim and M. Vogel. Pp. x, 201; 72 figs. New York, 1943 (Interscience Publishers, Inc., $4.00).—This book constitutes a noteworthy attempt to correlate the theory of luminescence and its applications. The task is a rather difficult one since the applications of luminescence involve a great deal of information which is still of an empirical nature.

Part I of the book deals with the history, theory, technique, and sources of luminescence. Descriptions and illustrations of apparatus are given. The properties of various groups of luminescent materials are discussed at some length.

Part II contains a treatment of the applications of luminescence. The material is divided into two main parts: fluorescence analysis and luminescence as a source of light.

In addition to extensive references a list of earlier books on luminescence is given. A useful tabulated list of important fluorescent materials is included also. H. M. CLARK.

Miscellaneous Scientific Intelligence.

A Life of Travels; by C. S. Rafinesque. Being a verbatim and literatim reprint of the original and only edition (Philadelphia, 1836). Pp. 292-360. Vol. 8, No. 2, 1944 (The Chronica Botanica Co., Waltham, Mass.; G. E. Stechert and Co., New York City, $2.50).—The reprint edition of this biography is timely as many critical papers have recently been devoted to Rafinesque; it is

particularly appropriate to review it here since Rafinesque was a substantial contributor to the first volume of Silliman's American Journal of Science in 1818-1819.

Rafinesque is generally known as an idiosyncratic naturalist. Many share the conception that, "In his crazy notions regarding the multiplicity of species, Rafinesque has no equals," but as Professor E. D. Merrill points out in the foreword, ". . . once his works do become available to a wider circle of working biologists, perhaps we may approach a truer evaluation of what he actually accomplished." Nor should we ". . . forget that as early as 1832 he forecast the general principles of organic evolution in his published statement. 'The truth is that Species and perhaps Genera also, are forming in organized beings by gradual deviations of shapes, forms and organs, taking place in the lapse of time. There is a tendency to deviations and mutations through plants and animals by gradual steps at remote irregular periods.'" To those who want first-hand information about Rafinesque, this reprint offers a chance for individual judgment of his status as a biological contributor. Thus, the first plant he encountered on arrival in this country was "new." Similarly, he refers to "Decandole" frequently —in reality, as Dr. F. W. Pennell points out in his critical index, the Swiss botanist, de Candolle. All in all, his peregrinations, interests, and opinions bring him close to the reader.

Furthermore, the story of Rafinesque's life, as here told, has wide appeal. For example, ". . . it appears that who ever travels by sea in the cradle or very early, is never liable afterwards to this singular disorder (sea sickness). It seems also that whoever can ride backwards in a coach without difficulty is not liable to it; but whoever cannot, will suffer sadly from it. . . . Having never read any where these two observations of mine, I venture to notice them here, that they may be confirmed by extensive experience." Rafinesque does not even consider the possibility that his observations might be rejected as erroneous! But that same confidence enabled him to amass a small fortune in Sicily by preparing and shipping dry Squills for use as an emetic. The account of the loss of all he possessed in a shipwreck off New London on his return to this country in 1815, his comments on co-education in Kentucky—"then began my lectures on Natural History to a class of ladies and students . . .", are among the many passages which make delightful reading. DANIEL MERRIMAN.

Chemical Engineering Thermodynamics; by BARNETT F. DODGE. Pp. 663; 182 figs, New York, 1944 (McGraw Hill Book Co., $6.00). —Here is a thorough and mathematical treatment including a complete and careful explanation in English. The first two chapters cover the fundamental concepts and the two fundamental hypo-

theses, or "laws," with the review of some mathematical relationships to be used in the later chapters. The discussion is clearly intended for the advanced student, and it would probably not be correctly understood by the beginner. Although it is clearly stated on page 20 that "work is concerned only with action against forces external to the system," and on page 24 that "energy which is stored in a system, ... is not to be associated with the term heat," the symbols for work and for heat are each equated to changes taking place within the system. This tends to be confusing to the beginning student.

The third and fourth chapters cover mathematical development of the first and second laws in an orthodox manner except for a redefinition of the function F on page 151. At no other place is any attempt made to cover surface, electrical or effects other than heat, compression and chemical. This is a shortcoming which can be easily remedied by the instructor. The pressure-volume-temperature relationships and equations of state are presented in chapter 5 and used in chapter 6 to develop the thermodynamic properties of fluids.

The last seven chapters bear titles that a chemical engineer would expect to find in a text on unit operations. But Dodge has correctly covered the application of thermodynamics to chemical engineering problems in these chapters and by use of the chapter titles has emphasized the importance of thermodynamics to the chemical engineer. The treatment and information presented are invaluable to anyone dealing with these operations or teaching chemical engineering

The reviewer has used the text successfully in a course for graduate students in chemical engineering. The book appears to have been written primarily for this purpose or for a reference volume for practicing engineers who will find it useful not only in their practical work but also as a means for reviewing their fundamental principles. The complete explanations and large number of examples demonstrating the application of the principles and the derived equations make the volume ideal for self-study. With skillful handling and the addition of problems it might prove satisfactory for undergraduate work, but it appears not to be arranged for this purpose and is burdened with many equations of special application.

There are surprisingly few places where the reviewer would ask for further explanation. The stable and neutral equilibria of Gibbs appear to have been merged into a single concept which may have lead the author to state that $dF=0$ is a criterion for equilibrium but that $\Delta F=0$ is not.

Chemical Engineering Thermodynamics is an excellent treatment

recommended as essential to all practicing chemical engineers, teachers, and advanced students. GEORGE GRANGER BROWN.

Old Oraibi, A Study of the Hopi Indians of the Third Mesa, by MISCHA TITIEV. (Papers of the Peabody Museum of American Archaeology and Ethnology, Vol. XXII, No. 1, 277 pages. Cambridge, 1944) —This long awaited monograph fulfills expectations in offering the most complete account of a Hopi town to date. It follows the usual pattern of Pueblo studies in that the bulk of the material presented is concerned with ceremonialism. The next most extensive topic covers kinship and social organization A well integrated chapter on "Economic Background" rounds out the picture.

In Titiev's analysis of the marriages of 826 individuals, it is revealed that 34 per cent of the people studied have participated in from one to eight divorces. This will come as a surprise to many who believe divorce was comparatively rare.

His discussion of the feud that brought about the disintegration of Oraibi raises many interesting questions and offers a possible solution to some archaeological problems. The author suggests that such intra-Pueblo conflicts may have caused the sudden abandonment of some of the large Pueblo ruins of the Classic Period.

The material on warfare and its associated rituals, although limited, is most welcome, as there is little information on this phase of Pueblo culture in previous literature.

It is regrettable that the author was unable to devote more time to the study of material culture. It seems to the reviewer that this is the most neglected phase of Pueblo culture. Although some information is scattered in many papers, there is need of complete studies of the material culture of several Pueblo groups.

JOHN M. GOGGIN.

PUBLICATIONS RECENTLY RECEIVED

New York State Museum Handbook 19, Guide to the Geology of the Lake George Region; by D H Newland and H. Vaughan Issued September 21, 1943 Bulletins as follows: No. 325. Geology of the Willsboro Quadrangle, New York; by A. F. Buddington and L. Whitcomb, 1941; No. 326 Geology of the Wellsville Quadrangle, New York; by J G Woodruff; No. 327. Paleontology and Geology; by R Ruedemann and B F. Howell, Albany, 1942.

The Theory of Resonance and Its Applications to Organic Chemistry; by G W. Wheland. New York, 1944 (John Wiley and Sons, $4.50).

Outline of the Amino Acids and Proteins, edited by M. Sahyn, et al. New York, 1944 (Reinhold Pub. Corp., $4 00).

Mississippi State Geological Survey. Bulletin 59. Mississippi Minerals; by W. C. Morse, University, 1944.

U. S Geologcal Survey: 60 Topographic Maps.

American Journal of Science

MARCH 1945

SEDIMENTATION IN SOUTH CAROLINA PIEDMONT VALLEYS.

STAFFORD C. HAPP.

ABSTRACT. Valleys of the South Carolina Piedmont are narrow and youthful in form, but their flood plains are being aggraded by deposition of sand and reddish, micaceous, sandy silt, which are believed to be the products of soil erosion during the agricultural period of about 150 years The "modern" deposits cover a dark topsoil horizon, believed to represent the more stable alluvial surface prior to white settlement and clearing of the forests. The average thickness of "modern" deposits is about 4 feet, which is equivalent to removal of about 3.1 inches from the tributary uplands. Erosion surveys by Soil Conservation Service methods have indicated about twice this amount of soil loss. The valley sedimentation, and especially sand deposition, causes a major part of frequent flood damage on about 80,000 acres of corn land and about 40,000 acres of cleared pastures. The potential agricultural value of an additional 180,000 acres of bottom lands, now used only for woodland pasture but partly cultivated in the past, is also being progressively reduced by the sand overwash. Soil conservation practices on the uplands, as now advocated by the Soil Conservation Service and other agencies, may reduce valley sedimentation rates somewhat, but any major improvement evidently will require more direct reclamation measures.

INTRODUCTION.

SOIL erosion has been the subject of extensive publicity in the United States during the past decade, and sedimentation has often been mentioned as one of its harmful effects. Undoubtedly soil erosion has increased the sediment loads of many streams and contributed much of the sediment deposited in water supply reservoirs. The relations between soil erosion and sedimentation in major rivers and valleys, and in harbors, are not yet clearly established. There are, however, some parts of the United States where the valleys of creeks and the smaller rivers have been appreciably aggraded since white settlement, apparently as a result of increased erosion rates following clearing and cultivation of the tributary uplands.[1]

[1] For a general discussion, see Happ, Stafford C, Rittenhouse, Gordon, and Dobson, G C.: 1940, Some Principles of Accelerated Stream and Valley Sedimentation. *U. S. Dept. Agric. Tech Bull.* 695, 133 pp.

One of the areas of notable aggradation of small streams and valleys is the South Carolina Piedmont (Text Fig. 1). A systematic reconnaissance of valley sedimentation conditions in this area was made by the writer during the winter of 1936-37. Test borings were made in 45 valleys, including most of those over ten miles in length, and observations covered about one per cent of all the valley areas. A few months later more detailed studies were made in the valleys of Ferguson Creek

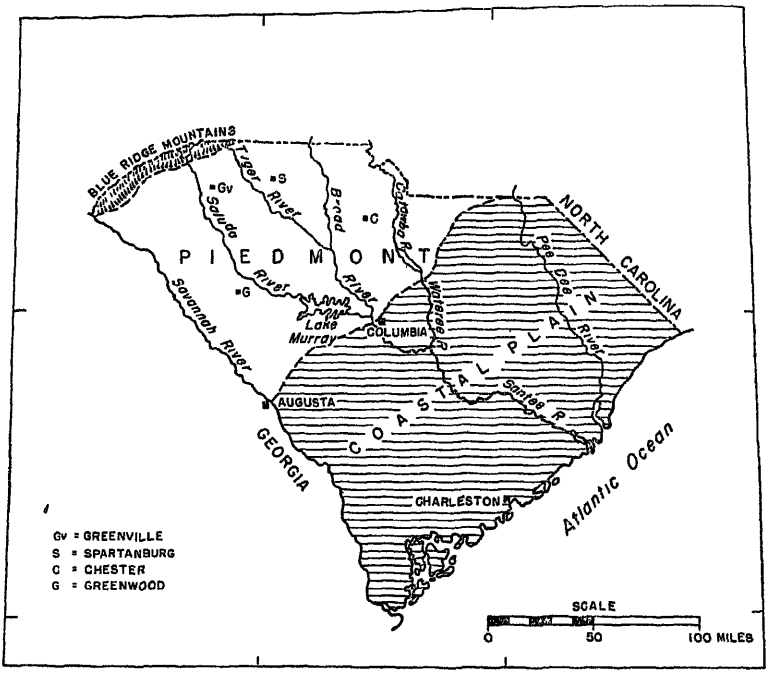

Fig 1 The Piedmont in South Carolina, in relation to other physiographic provinces and major river systems

and Tyger and South Tyger Rivers, with the assistance of Gordon Rittenhouse, Earl H. Moser, Jr., and Mark P. Connaughton. The detailed studies were extended to the valley of Little Ferguson Creek, a tributary of Ferguson Creek, by Eldon M. Thorp in 1939-40. These studies were made near the central part of the South Carolina Piedmont, in valleys which appear to be reasonably representative of average conditions, and they support the general conclusions originally derived from the more widespread reconnaissance.

IDENTIFICATION OF MODERN FLOOD PLAIN DEPOSITS.

Practically all the Piedmont valley flood plains are covered with "modern" sediment, which is defined as the sediment deposited under the influence of accelerated soil erosion since white settlement. The upper two or three feet of alluvium is usually brown or reddish-brown, similar in color to the subsoils of adjacent gullied uplands, and these reddish-brown deposits are generally recognized as the products of accelerated soil erosion. In the upper few miles of many valleys, where stream channels are generally less than five feet deep and flood plains less than 200 feet wide, the reddish-brown deposits commonly lie on a dark gray horizon which is the buried, pre-modern alluvial topsoil, underlain by lighter gray or yellowish subsoil. This vertical sequence shows that flood plain aggradation has buried a former more stable surface, on which a definite topsoil horizon had been developed from silty vertical accretion deposits. The silty vertical accretion deposits rest on sands accumulated by earlier lateral shifting of the stream. Partial burial of fences and young trees indicates rates of deposition that would account for all of the reddish-brown deposits in less than the average period of 150 years of accelerated soil erosion. In many places the buried old topsoil can be traced laterally and shown to be coextensive with the topsoil still partly preserved on the lower slopes of the valley sides. In these places the reddish-brown deposits surely represent the accumulation during the period of accelerated soil erosion.

When traced down the valleys, the buried old topsoil is found at progressively greater depths beneath the flood-plain surface, and within a few miles it usually passes beneath the ground-water table. Nearly all of the alluvium below the water table is gray, and color mottling is a distinctive feature. Where the modern deposits are now below the water table they usually have this gray color, and here the brown deposits represent only part of the modern sediment. This is the condition throughout most of the Piedmont valleys, and it is a major factor in interpretation of the sedimentary sequence because the gray beds usually are exposed in stream banks at about the water level, which controls the ground-water table. When moist the gray sediment is dark, or almost black, and usually it is impossible to see that this dark horizon does not overlie a lighter subsoil as would be expected if it were actually an old topsoil. The true relations become apparent when borings

are made to study the sediment below the water table, where examination is not otherwise possible.

Where the modern sediment is partly below the water table a distinct buried topsoil horizon, with a lighter-colored subsoil under it, was found in only about ten per cent of nearly 200 test borings. Nearly half of these borings show a moderately-dark, gray horizon at depths similar to those of the few old topsoil horizons, and in reasonable agreement with a uniform downstream projection of the contact of brown modern sediment on the topsoil, but with no evidence of an underlying subsoil; the other half of the borings failed to show even a distinctly dark-gray horizon. If the few definite old soil horizons, and the larger number of dark gray horizons at similar depths, be taken as an indication of the depth of modern sediment, this average depth is about four feet.

Other studies have established that, prior to the present agricultural development, valley flood plains were generally sufficiently stable for development of alluvial soil horizons throughout the eastern and central United States. Failure to identify such soils in most of the South Carolina flood-plain borings may be due to any one, or any combination, of three conditions:

1) The flood-plain deposits include much coarse, well-washed sand, which caves badly in auger holes below the water table. The dark, soil-like horizons are often of fine material which may be easily washed off the auger or mixed with sand from higher horizons. Possibly the masking effect of the loose sand has been sufficient to prevent recognition of a lower soil horizon in many places;

2) The Piedmont valleys are relatively narrow, and are frequently flooded. Possibly floods and streambank erosion were sufficiently active, even under pre-agricultural conditions, to make the flood-plain surfaces less stable than in other regions where valleys are relatively wider or floods less frequent and less violent. The many bedrock shoals and irregular gradients also testify to the youthful character of the valleys, which would indicate relative instability of the flood plains. Under such conditions dark alluvial topsoils may never have developed over most of the Piedmont flood plains;

3) The narrow valleys and comparatively steep gradients are conducive to high velocities of overbank flood flow, and consequent active scouring of the flood-plain surface. A large part of the valley sediment is in the form of bars or splays[2]

[2] See page 24, *U. S. Dept. Agric. Tech. Bull.* 695, *op. cit.*

of coarse sand, indicating overbank deposition from currents of considerable velocity. Fresh scour channels are also common on the flood plains at many places. It may be, therefore, that the flood-plain surface has been extensively scoured by overflow waters during the period of modern sedimentation, at many times and many places, and the sediment accumulation may be largely in the form of replacement of former alluvium thus scoured away. In this process much of any former alluvial soil horizon may have been destroyed by scouring, although the flood plains as a whole have been aggrading.

It is reasonably certain that each of these explanations applies in various places, but present information is not adequate to determine which may have been dominant, on the whole. The few definite buried soil horizons, and the less certain dark horizons at similar depth, are believed to provide a fair guide to the average thickness of the modern sediment, but it is not yet possible to interpret the Piedmont valley sedimentation in as much detail, with as much assurance, or in as exact quantitative terms, as can be done in many valleys in other parts of the country.

In a few places multiple dark horizons have been found, separated by lighter-gray strata which are often more sandy, but none of these places shows more than one definite soil profile sequence, with unmistakable subsoil development. Probably many of these dark horizons represent swampy deposits, in which considerable organic coloring material was preserved, separated by more sandy deposits which filled the low swampy places during major floods. Such dark horizons have no certain significance as time markers. Some appear to be in the modern sediment, and some among the older flood-plain deposits. Perhaps some of the older dark horizons are similar in age to the buried organic deposits reported in the valley heads and upland dales by Eargle[3] and which Bryan[4] has suggested may be associated with widespread periglacial Pleistocene climate. Text Fig. 2 illustrates conditions in one of the places where the pre-agricultural topsoil can be identified most convincingly, and a lower, older deposit of high humus or organic content is also present.

[3] Eargle, D. Hoye: 1940, The Relations of Soils and Surface in the South Carolina Piedmont, *Science*, Vol. 91, pp. 337-338.

[4] Bryan, Kirk: 1940, Soils and Periglacial Phenomena in the Carolinas, *Science*, Vol. 91, pp. 523-524.

CONDITIONS IN MAJOR VALLEYS.

In the valleys of the Savannah, Broad and Wateree Rivers, which are influenced by large mountainous headwater areas, there are many fresh sand-bar deposits along the channels and spread on the flood plains, but it is uncertain whether or not progressive flood-plain or channel aggradation is taking place. Most of the fresh deposits appear to be of transitory character, subject to removal during later floods, and possibly equalled by flood scouring and bank erosion on other parts of the flood plains. The amount or proportion of sediment carried by the main rivers from the Piedmont into the Coastal Plain is also unknown.

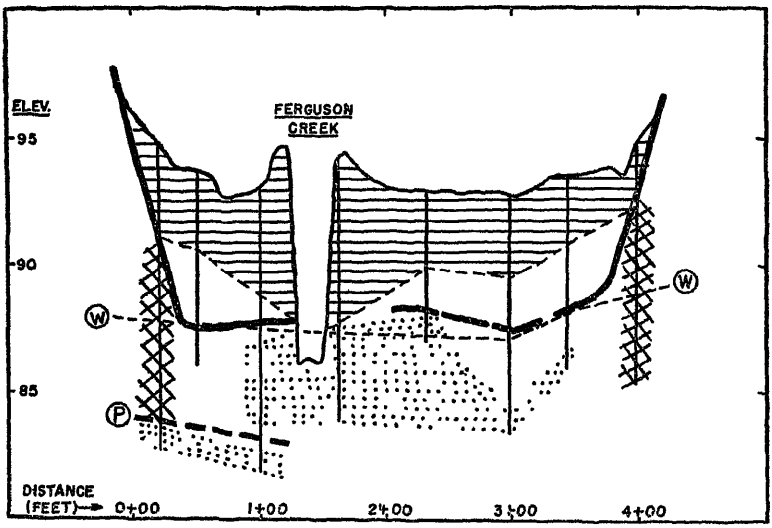

Fig 2 Cross section of Ferguson Creek Valley, about 400 feet above confluence with South Tyger River, Spartanburg County, S C Test borings (vertical lines) show that the dark, pre-agricultural topsoil (heavy solid line), which is underlain by a lighter subsoil near the valley sides, can be traced into a dark alluvial horizon, but lacking a definite subsoil, which extends across most of the flood plain (broken line) The ground water table (W) is close to the "old soil" horizon, and the prominent color change usually occurring near the water table often obscures the soil horizon Part of the "modern" alluvium is reddish and clearly stratified (horizontal ruling), and hence is too recent to have been modified greatly by soil processes. Sand (dotted pattern) probably consists chiefly of old channel deposits, and the fact that it is mostly below the "old soil" and present stream bed indicates that there has been no great channel migration or aggradation during accumulation of the "modern" overbank deposits. Micaceous, poorly-sorted colluvium (cross-hatched), obviously of local derivation, underlies the "old soil" at the valley sides, and in some places overlies a dark peaty alluvial horizon (P) which may be an "older" buried soil.

The Saluda River also has an appreciable area of mountains in the upper part of its drainage basin, but the mountainous area is smaller in proportion to its Piedmont area, and in sedimentary features the Saluda valley appears to be intermediate between the smaller Piedmont valleys and those of the larger rivers.

Artificial lakes, impounded by dams built to provide water power, occupy a large part of the major valleys, and are major factors in the sedimentation conditions. Much sediment is accumulating in the lakes, but no attempt was made to measure this during the reconnaissance of valley sedimentation conditions.

THE AMOUNT OF SEDIMENT.

Soil surveys show that bottomlands comprise about six per cent of the South Carolina Piedmont.[5] An average depth of four feet of modern sediment, covering six per cent of the area, would be equivalent to an average removal of 3.1 inches of soil from the remainder or upland part of the area. This is based on the assumption that upland soil and valley sediment have the same weight per unit volume, which is a reasonable approximation. The period of accelerated soil erosion has probably averaged about 150 years, and hence the average rate of sediment accumulation appears to have been about 1.1 acre feet per year per square mile of contributing area. The present rates of erosion and sedimentation are probably higher than this average, as erosion is partly a cumulative process. If the rate of increase has been uniform the present rate should be twice the average, or 2.2 acre-feet per square mile per year.

Stream channels occupy between ten per cent and fifteen per cent of all Piedmont valleys, according to reconnaissance data. The amount of modern sediment in the channels cannot be determined by direct observation, as it can in many places on the floodplains, because channel deposits are transitory and subject to alternating removal and replacement, especially during major floods. Old survey records in this area have not been found adequate as a basis for measuring the changes in stream-bed elevations over specific periods of years. In many places the stream beds are now higher than the pre-modern

[5] Computed from data on surveys of 16 counties, which together comprise about 90 per cent of the Piedmont plus small parts of the adjoining Coastal Plain and Blue Ridge Mountains

alluvial soil, however, and this clearly shows that the stream bed has been aggraded. Stream aggradation is also indicated by the fact that the ground-water table is now higher, in many places, than the base of the modern flood-plain deposits.

In some places borings have penetrated entirely through the alluvium to the underlying bedrock, and in several such places the modern sediment represents about one-third of the entire thickness of flood-plain deposits. If these instances are typical, and if the pre-modern channels were similar to the present channels in depth, as seems probable, then the modern channel aggradation has probably been at least half but not more than twice as much as the flood-plain aggradation. The scanty evidence will not justify more precise estimates, but these approximations appear to be reasonable. If the channel deposits are twice as thick as the overbank deposits, this might increase the average thickness of all valley deposits by as much as fifteen per cent; if the channel deposits are only half as thick as those overbank, this might decrease the estimate of average thickness for all valley deposits by as much as seven and one half per cent. Such corrections would be well within the range of probable accuracy of the overall estimates.

The sedimentation rates are higher where the valleys are inundated by mill ponds or larger reservoirs. In the aggregate the reservoirs may inundate an area twenty per cent as great as that of all the Piedmont bottomlands, but this includes appreciable areas of sloping valley sides. From limited data now available, it appears that the average depth of sediment in all reservoirs is not more than two feet, which, with allowance for difference in density, would be equivalent to only about one and one half feet of flood-plain deposits. The average is held down by the apparent small average depth of sediment in Lake Murray, on the Saluda River, which has at least half the aggregate reservoir area.[6]

Some of the larger reservoirs receive a major part of their sediment from North Carolina, as well as some from the mountain area of South Carolina. The average age of the reservoirs is only about fifteen per cent of the entire period of accelerated sedimentation, but some part of their sediment is equivalent to what would have been deposited on the flood plains within the reservoir areas if these had not been inundated. It appears,

[6] Eakin, Henry M.: 1940, Silting of Reservoirs (Revised by Carl B. Brown), *U. S. Dept. Agric. Tech. Bull.* 524, 168 pp. See p. 128.

Fig 1—A small Piedmont stream channel badly choked with sand Ferguson Creek, Spartanburg County, S C (Photo by Rittenhouse)

Fig 2—Willow tree partly buried by sedimentation on Ferguson Creek flood plain, Spartanburg County, S C The tree had been partly girdled, and the section from which bark was stripped had then been partly covered by the new deposits This is in an area where deposition was unusually rapid at the time, because of a local "plug" of sand in the small stream channel shown in figure 1 (Photo by Rittenhouse)

Figs 1 and 2—Fresh sand "splay" deposits, covering vegetative growth of the previous season, on the flood plain of the South Tyger River, Spartanburg County, S C In places four feet of coarse, gravelly sand had been deposited on the grass sod, during one winter season Photographed 2-16-1937

therefore, that the total volume of reservoir deposits is probably equivalent to an addition of not more than 0.2 foot to the average depth of the valley deposits, or five per cent of all the modern Piedmont valley sediment.

RELATION OF SEDIMENTATION TO RATES OF SOIL EROSION.

Soil erosion surveys indicate that the average amount of soil removed from the upland part of the South Carolina Piedmont has been about six inches during approximately 150 years of agricultural use. This is the amount computed for the drainage area above Spartanburg Municipal Reservoir,[7] on the South Pacolet River, in the upper part of the Piedmont. The drainage area of 91 square miles is less than one per cent of the entire South Carolina Piedmont, and is not representative of the whole region in all respects, but field observations indicate that the average erosion rate may be fairly representative.

In the much larger Lloyd Shoals Reservoir drainage area of 1,414 square miles, in the Piedmont of northern Georgia where observations suggest that erosion is somewhat more active than in South Carolina, erosion survey data indicate an average depth of soil removal of 6.4 inches.[8] Erosion surveys also show removal of 4.8 inches from the area above University Lake near Chapel Hill[9] and 4.4 inches above Lake Michie near Durham,[10] both in the North Carolina Piedmont where erosion appears to have been less severe than in South Carolina. The probable accuracy of erosion rates computed from these surveys is subject to a number of factors which cannot yet be evaluated, but the data appear to be consistent in supporting an estimate of about six inches of surface soil loss for the South Carolina Piedmont.

The estimated 3.1 inches of soil loss from the uplands, represented by Piedmont valley deposits, is equivalent to fifty-two per cent of the six inches of soil loss estimated from erosion

[7] Bass, T. C., and Martin, I. L.: 1940, Erosion and Related Land Use Conditions on the Spartanburg Municipal Reservoir Watershed, South Carolina, *U. S. Dept. Agric.*, 16 pp.

[8] Montgomery, P. H.: 1940, Erosion and Related Land Use Conditions on the Lloyd Shoals Reservoir Watershed, Georgia, *U. S. Dept. Agric.*, 26 pp.

[9] Bass, T. C., and Martin, I. L.: 1939, Erosion and Related Land Use Conditions on the University Lake Watershed, Chapel Hill, North Carolina, *U. S. Dept. Agric.*, 16 pp.

[10] Martin, I. L., and Bass, T. C.: 1940, Erosion and Related Land Use Conditions on the Lake Michie Watershed, near Durham, North Carolina, *U. S. Dept. Agric.*, 19 pp.

surveys. If the channel deposits average twice the thickness of flood-plain deposits, thus increasing the valley deposits by fifteen per cent, and if reservoir deposits amount to five per cent more, then the total modern sediment in the Piedmont valleys would be equivalent to an average upland soil loss of approximately 3 7 inches, or sixty-two per cent of the estimated amount of soil erosion. If the channel deposits average only half as thick as the flood-plain deposits, this might more than balance the amount in reservoirs, but the equivalent average depth of upland erosion would be reduced only two and one half per cent to 3.0 inches or fifty per cent of the estimated upland erosion. The remaining thirty-eight per cent to fifty per cent of the upland erosion, according to the different estimates, presumably is represented partly by colluvial deposits on the lower parts of slopes and behind fences or other local obstructions, and partly by sediment carried out of the Piedmont into the Coastal Plain valleys and thence partly to the bays along the coast. Present data are not adequate to show the distribution of these two parts of the eroded material.

The significance of the comparisons between sedimentation and soil erosion rates lies not in the specific figures derived, which are only rough approximations, but in the evidence they provide of the magnitude of the erosional and sedimentary processes. Techniques have been developed for mapping the distribution of various degrees of severity of soil erosion, and for measuring the amount of related sedimentation on valley flood plains or in artificial reservoirs, but application of these techniques to large areas involves a vast amount of labor. It becomes necessary, where surveys cover more than a few hundred acres, to rely on a few sample measurements or interpretations, and to expand these results by methods which are partly subjective. These difficulties cannot be eliminated in the near future. Much experimental data on erosion rates is being compiled for small plots, but as yet there is no reliable basis for using such data in estimating quantitatively the effectiveness of erosion-retarding measures on uplands in improving bottom land conditions for agriculture, or in reducing sedimentation rates in reservoirs or navigable waterways. Evaluation of the relation between erosion and sedimentation rates requires quantitative data on the distribution of the eroded soil, as well as on the effectiveness of various possible remedial measures. The latter cannot be obtained without

experimentation on a full field scale, but in order to judge whether and where such experimentation is worthwhile, it is first necessary to know the present conditions of sediment distribution. Estimates such as these for valley sedimentation in the South Carolina Piedmont are intended as an approach to such comparative data, which are not yet available for many areas of similar size.

IMPORTANCE OF SAND DEPOSITION.

According to field identification of samples from random test borings in 17 representative valleys, the flood-plain deposits to an average depth of seven feet consist of thirty-five per cent sand, twenty-six per cent silty sand, thirteen per cent sandy silt, eighteen per cent silt and eight per cent clay-silt. The proportion of sand in each of these textural classes can be estimated only very roughly, but it appears that sand forms more than half of the flood-plain deposits. Most of the borings were made where the modern deposits are thicker than the general average, so these textural figures are chiefly representative of the modern deposits. Much of the sand is medium to coarse, and contains fine gravel. Sand deposits averaging at least several inches thick cover forty-five per cent of the flood-plain surface at the places visited in the reconnaissance. These sand deposits obviously reduce the productive value of the land although present data are not sufficient for a quantitative evaluation of the soil damage.

Sand is also responsible for the aggradation of the stream beds, with resulting increased frequency of overbank flooding, and swamping of parts of the flood plains. It has been noted in an earlier paragraph that there is fairly definite evidence of the channel aggradation, and that is seems most reasonable to estimate that this has been similar in amount to the aggradation of the flood-plain surface although it is difficult to obtain a reliable measure of the changes within the channels. In some places the smaller stream channels are now completely filled with sand, so that even the ordinary stream flow spreads over the flood plain in shallow distributary channels. In places these conditions are reported by local residents to have developed within the memory of people still living, but they are only of local extent. Such local channel occlusion may also have been common prior to the present accelerated sedimentation, but there can be no doubt that the large volumes of sand enter-

ing the streams from new, deep gullies, contribute to the frequency or the likelihood of such local channel filling. Throughout most of the valleys it is uncertain whether the present stream channels have larger or smaller discharge capacities than the pre-modern channels, but whatever these relative conditions, the amount of sand in the present channels obviously reduces their capacity and thus contributes to the frequency and depth of overbank floods.

The extent of damage caused by the deposition of the silty sediment, which forms nearly half of the modern valley deposits, is difficult to appraise. It has commonly been assumed that the silty deposits are relatively infertile because they include much subsoil material, and have a lower organic content than the former alluvial soils. There is, however, still uncertainty as to how much of the flood plains in this area were previously covered by topsoils of relatively high organic content, and it is also evident that there must be a considerable proportion of upland topsoil material in the finer modern valley deposits. Where not excessively sandy or swampy, the modern deposits produce good corn crops if not flooded out during the growing season. Practically none of the original alluvial soil is still at the surface, so that its productive capacity cannot now be fairly compared with that of the modern sediment of similar texture, under similar conditions of drainage, overflow and cultivation.

ECONOMIC IMPORTANCE.

The only important economic effect of the valley sedimentation appears to be its relation to agricultural use of the bottom lands. Sand accumulation in the stream channels tends to increase the height and frequency of overbank floods, which destroy considerable amounts of farm crops, and filling of drainage ditches interferes with adequate drainage and thus reduces the productivity of the valley lands. Sand deposits on the flood plain are often thick enough to cause considerable loss of productive capacity of croplands or improved pasture, as well as burying young crops. The overbank deposits of silt and clay are apparently less harmful, although they may bury and destroy young crops or pasture grass at times, and their effect on the long-time productivity of the land has not yet been adequately studied. The sedimentation damage occurs chiefly during floods, and cannot be very precisely separated from the damage by flood water, but it is commonly recognized

that the sedimentation is the cause of a major part of the total flood damage. This has been noted in various County Soil Survey Reports.[11, 12, 13]

No dollars-and-cents evaluation of the sediment damage can yet be made, but some idea of the magnitude of the problem can be inferred from the areas of present or potential farm land involved. The entire South Carolina Piedmont comprises about 6,500,000 acres, of which about six per cent, or 400,000 acres, lies in the valleys. The 1936-37 reconnaissance indicated that about twenty per cent of the valleys, or 80,000 acres, were used for corn, the only cultivated crop grown extensively, and about ten per cent or 40,000 acres were in open pasture of various stages of improvement. About twenty-five per cent or 100,000 acres are occupied by stream channels and reservoirs, or by small, isolated strips of flood plain that are of little value because of their inaccessibility. This leaves about 180,000 acres that are occupied by woodland or by wild pasture, but most of which would be suitable for more intensive agricultural use if it were not for the excessive flood and sedimentation damage. A major part of the present crop land and improved pasture could also be improved considerably if the rates of sedimentation could be reduced.

This paper is an outgrowth of studies which were expected to provide part of the physical data for an investigation of the feasibility of remedial measures. These further investigations have not been made, and it cannot be decided yet whether it would be economically feasible to control or reduce the sedimentation sufficiently to allow more intensive agricultural use of the valleys. Presumably any remedial program should involve either (1) detention basins or vegetation screens to concentrate sedimentation on selected areas of low value, in order to prevent much of the sediment from reaching more valuable lands farther down the valleys, (2) training dikes or jetties to direct sediment-carrying water to selected low

[11] Taylor, F W., and Rice, Thomas D · 1902, Soil Survey of the Abbeville Area, South Carolina, *U S. Dept Agric. Field Operations of the Bureau of Soils*, 1903, pp. 273-289; reference on page 285.

[12] McLendon, W. E : 1912, Soil Survey of Anderson County, South Carolina, *U. S. Dept. Agric Field Operations of the Bureau of Soils*, 1909, pp. 449-481; reference on page 468.

[13] Latimer, W. J , Deeter, E. B , Perkins, S. O , Hearn, W. Edward, and Van Duyne, Cornelius: 1921, Soil Survey of Spartanburg County, South Carolina, *U. S. Dept Agric. Field Operations of the Bureau of Soils*, 1924, pp 409-449; reference on page 446

areas which would thus be built up by sedimentation until they could be farmed with less hazard of overflow and with better drainage, or (3) introduction of erosion-retarding or soil conserving methods on the uplands to reduce sediment production and hence ultimately reduce rates of sedimentation in the valleys.

The latter method would seem to be most logical as a long-time program, and would be in accord with present objectives and policies of the Soil Conservation Service. It is doubtful, however, whether present types of Soil Conservation Service programs will affect the general erosion rates sufficiently to provide major benefits in the valleys. One of the most serious difficulties is the fact that much of the sand, which is especially harmful, is produced from deeply gullied lands that are often of such low potential value that their reclamation is uneconomical.[14] Possibly more immediate improvement could be achieved by some combination of detention basins or barriers and training jetties, with upland soil conservation and gully control programs to help maintain and eventually increase the improvements obtained by more direct methods of valley reclamation. Probably some full-scale experimentation will be necessary before any adequate and sound remedial program can be specifically defined.

[14] The gully problem has been discussed by Ireland, H A, Sharpe, C. F S, and Eargle, D. H · 1939, Principles of Gully Erosion in the Piedmont of South Carolina, *U S Dept Agric Tech. Bull* 633, 142 pp.

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A REVIEW OF THE FOSSIL FISHES OF CHINA, THEIR STRATIGRAPHICAL AND GEOGRAPHICAL DISTRIBUTION.

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ABSTRACT A summary of the present knowledge of fossil fishes in China After a brief review of the historical development of research on fossil fishes, all known forms are enumerated in stratigraphical order Their geographical distribution is made clear by a map showing all the main sites described in the text. A simplified systematic review is given at the end of the paper.

Contents:

1. INTRODUCTION.

THE study of fossil vertebrates in China was begun with the description of mammalian teeth of Cenozoic and Psychozoic age, purchased from the druggists or indirectly collected from other sources. The early descriptions of fossil mammals of China by Koken, Owen, Schlosser and others were based on material of such origin. During this time no fossil fish was recorded.

Even in the time of Anderson's and Zdansky's field work in China, and Andrews' expedition in northern China (Mongolia),' attention was chiefly paid to the discovery of other vertebrates, mainly reptiles and mammals. Some occasional finds of fossil fishes can only be regarded as a sort of by-product.

Nevertheless, a number of fossil fish localities were discovered during this time which yielded many interesting forms, such as *Sinamia zdanskyi*, described by Stensio, the fossil fish in Taiku described by Tchang, and the fossil remains from Sui-yuan described by Hussakof, etc. During the last fifteen years great progress has been made in the discovery of fish remains. For the first time, we have made a real excavation for collecting fishes only, at the so-called Locality 14 near Choukoutien.

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This locality has yielded several thousands of fish remains. In Shanwang, eastern Shantung, we have discovered a rich fish level. More recently, discovery of Devonian placoderms was made through a number of geologists while working in southern China.

From all these facts, we begin to have a fairly good idea concerning the fish fauna of China. Since the described literature of fossil fishes is so scattered, and a great number of fish specimens secured by the Geological Survey of China are not yet described, it is desirable to give a short account of our knowledge of fossil fishes in China, especially concerning the stratigraphical and geographical distribution.

2. HISTORICAL REVIEW.

Fossil fishes have been known to the Chinese for many centuries. The genus *Lycoptera,* and fishes of similar kinds from various provinces in northern China, were collected by natives and sold to curio-dealers. They were prepared and framed by those dealers and considered as treasures. A short account of this has been published by H. T. Chang (1921, pp. 240-243) in his monograph entitled "Lapidarium sinicum."

In the early days of the field activities of the Geological Survey of China, fish remains were found by many geologists from a number of provinces, chiefly in northern China. With the exception of *Lycoptera,* they are represented only by isolated scales and fragmentary parts of the skeleton. Most of these remains belong to ganoids. They were sent to England for determination, but the results are not yet published.

The fish remains from China discovered by the Central Asiatic Expedition were determined by Hussakof (1932), and those collected by Tan and Zdansky were described, Stensio (1935), (probably only a part of the collection included in this memoir). A part of the fish remains from Sinkiang discovered by P. L. Yuan, of the Sino-Swedish Expedition, were described by Yuan and Koh (1936). The collection of fossil fishes recently made by the National Geological Survey of China is mostly not yet studied. The first announcement of the discovery of Devonian fishes was made by the late Mr. Y. S. Chi (1940), and some others were collected by the writer.

In view of the richness of the fossil fish fauna in China, further collection and proper study of them are of outstanding importance both for stratigraphy and vertebrate paleontology.

3. IMPORTANT FISH-BEARING HORIZONS.

We shall now enumerate the known fish-bearing horizons in China, from old to young, stratigraphically. (cf. Table I.)

1. *Lower Devonian from Yunnan with Cephalaspis indet.* The presence of *Cephalaspis* remains has been known for many years through the findings of members of the Geological Survey of China. A fine specimen was presented to Doctor Grabau who briefly mentioned it in his Stratigraphy of China. This specimen is still kept by him in Peiping. But quite recently a rich *Cephalaspis*-bearing level has been discovered in Chuting, eastern Yunnan, by Y. C. Sun of the Southwestern Union University and by members of the Bureau of Mine Prospects under C. Y. Hsieh. I recently had the opportunity of examining the specimens of Sun and am convinced that they belong to the Cephalaspidae. The collection consists of several well preserved skulls and dermal plates of the trunk and tails. By careful collection, it is hoped entire skeletons will be found.

2. *Upper Devonian of Hunan and Yunnan with Bothriolepis sinensis.* The rich fish-bearing locality of Tiomachien, southwest of Changsha, Hunan province, was first discovered by Chi and Yeh. Later M. N. Bien and the writer made additional collections from the same spot. The late Chi, in a preliminary study, identified the remains as *Bothriolepis sinensis*, a form closely related to *B. canadensis*. The presence of apparently the same species from the same stratigraphical horizon was recorded later in several localities in Yunnan province. One of the localities is situated in the district Kungyang and others east of Kunming. They were discovered by P. S. Shiung and the late T. Y. Hsue respectively. Now both in the Geological Survey of China and in the Geological Institute of the Southwestern Union University in Kunming, there is a series of these specimens waiting for final study.

3. *Carboniferous fish bed in Sinkiang.* P. L. Yuan has discovered two main fish-bearing levels in the vicinity of Tihua in Sinkiang, the lower one of which belongs to Carboniferous age. Yuan (1935). The fish remains of the lower beds are, however, not yet described.

4. *The Sinosemionotus level in Sinkiang, middle Triassic.* This is the upper fish level of Yuan. Part of the remains were described by him and Koh as *Sinosemionotus urumchii* (1936). Recently, the latter author has found additional specimens from Sinkiang, probably derived from the same horizon.

TABLE I.

Geologic age	Fish remains	Locality	Remarks
Pleistocene	*Ctenopharyngodon idellus*	Loc 3 Choukoutien	
Upper Pliocene	Cyprinidae indet.		
	Ctenopharyngodon sp	Sanmen, Shansi	
	Hypophthalmichthys sp.		
	Carassius aaratus	Taiku, Shansi	
Lower Pliocene	Cyprinidae indet	Ertemte, Suiyuan, Nanning, Kwangsi etc	
	Barbus szechuanensis	Loc. 14 Choukoutien	
	Barbus brevicephalus		
Miocene	*Leuciscus miocenicus*		
	Barbus linchuensis	Shanwang, Shantung	
	Barbus scotti		
	Pseudorasbora macrocephala		
	Rhineastes grangeri	Tung Gur, Suiyuan	
	Cyprinidae indet	Hsiawanpu, Hunan, etc	Not yet published
Early Tertiary	Teleostei indet.	Wusu and Kusha, Sinkiang, Hengyang, Hunan etc.	Not published
	Pappichthys mongoliensis	Shara Murun etc.	
	Catostomus sp		
	Cyprinidae indet		
Cretaceous	*Lycoptera* sp	Jehol	
	Lycoptera ferox	Shantung, Jehol	
	Lycoptera sinensis		
	Lycoptera fragilis	Ondai Sair, Mongolia	
	Sinamia zdanskyi	Mengyin, Shantung	
	Mesoclupea showchangensis	Showchang, Chekiang	
	Mesoclupea globicephala		
Jurassic	*Lepidotus* sp nov.	Weiyuan, Szechuan	Not published
	Ganoids indet	Junghsien, Szechuan	
	Ganoids indet.	Central Kansu	
	Ganoids indet	N Shensi	Not published
	Ganoids indet	N Manchuria	
	Hybodus sp.	Yungteng, Kansu	
	Ceratodus szechuanensis	Weiyuan, Kuanyuan, Szechuan	
Upper Triassic	*Hybodus houtienensis*	Anning, Yunnan	
Middle Triassic	*Sinosemionotus urumchii*	Urumchi, Sinkiang	
Carboniferous	Fish remains	Urumchi, Sinkiang	Not published
Upper Devonian	*Bothriolepis sinensis* and other similar forms	Tiomachien, Hunan, Kunyang, Central Yunnan etc.	Not yet published Mostly not published
Lower Devonian	Cephalaspis indet.	Chueting, E. Yunnan	Not published

5. *The upper Triassic fish horizon from Yunnan.* The other Triassic fish level was made known by the finding of a spine of *Hybodus* from Anning, Yunnan. It has been described by me recently (1941). Indications of the presence of fragmentary fish remains from the same period were located in several other places.

6. *Jurassic Fishes.* In almost every level of the Jurassic deposits in China there are remains of fishes to be noticed. In most places, however, they are only represented by fragmentary specimens, apparently due to the rather primitive way of collecting. The following are the principal localities with ganoids and other fishes:

a. Ganoids from Manchuria.
b. Ganoids from northern Shensi.
c. Ganoids from Kansu.
d. Ganoids from Szechuan.
e. *Hybodus* sp. from Yungteng, Kansu and Kuangyuan in northern Szechuan.
f. *Ceratodus* from Weiyuan and Kuangyuan, Szechuan.

It should be noted that the ganoids from western Szechuan are represented by a number of well preserved specimens, at least one of them with even the detailed structure of the skull perfectly preserved. According to the determination of the late Y. S. Chi, it belongs to the genus *Lepidotus*, comparable with the species known from the Purbeck of England. The species is probably new. The untimely death of Chi interrupted the final description of the material which is now kept in the Cenozoic Laboratory of the Geological Survey of China.

7. *The Cretaceous fishes.* As noted above, the upper Jurassic or early Cretaceous fishes belong to the first-known fish remains in China. But even the best known form, *Lycoptera*, is not yet fully described. On the other hand, a thorough study of the member of the Amiidae, *Sinamia zdanskyi*, was published by Stensio (1935). The lower Cretaceous *Lycoptera fragilis* was described by Cockerell (1924-1925), and Hussakof (1932). The Cretaceous fish fauna seems generally marked by the extinction of true ganoids and dominance of *Lycoptera* and other modern looking forms. The genus *Lycoptera* is known chiefly from north China, throughout Jehol, Shantung, Shensi and Kansu provinces, but some of them, such as the fish remains of Kienyang in western Shensi may

belong to Tertiary age and should be considered as Clupedae or Cyprinidae. In Chekiang, however, fishes of lower Cretaceous age were described by Ping and Yen (1933) as *Mesoclupea showchangensis* and *M. globicephala* which represent the oldest known Clupedae in China, if the determination is correct.

8. *Early Tertiary fishes.* In the early Tertiary deposits of China, remains of fishes are still more abundant than in those of the Cretaceous. Unfortunately these are generally in a fragmentary state of preservation, often represented only by isolated scales, vertebrae and other bones. Complete specimens are rarely known. Most of these are not yet properly described. A number of specimens have been collected by the Central Asiatic Expedition and described by Hussakof as *Pappichthys mongoliensis* and *Catostomus* sp. from Shara Murun and Ulan Shireh formations in Suiyuan. They belong to the Eocene age. The presence of fish remains, mostly very fragmentary, is recorded in the early Tertiary beds of Sinkiang, Kansu, Shensi, Shansi, Honan, Hunan, Yunnan and many other places.

9. *The Miocene fish fauna.* The Miocene of China, although insufficiently known, seems to be rich in fishes. Hussakof has described one of the Siluridae, *Rhineastes grangeri*, from the Tung Gur formation of Suiyuan (1932). In the upper Miocene of Shanwang, eastern Shantung, at least four species of fishes were known, viz., *Leuciscus miocenicus*, *Barbus linchuensis*, *Barbus scotti* and *Pseudorasbora macrocephala*, all Cyprinidae (Young and Tchang, 1936). From Hsiawanpu, Hsiangshiang, in Hunan, fishes of the family Cyprinidae are also recorded.

10. *Pliocene fishes.* In the Pliocene of China, a rich fish fauna occurred in the Locality 14 of Choukoutien. It is represented by thousands of well preserved individuals, but of only two species, *Barbus szechuanensis* and *Barbus brevicephalis* which were described by Chang (1937). From the Pliocene beds of Ertemte (Schlosser, 1924) and Nanning, etc., remains chiefly of Cyprinidae, in a rather fragmentary state, were reported.

11. *Upper Pliocene fishes.* In the upper Pliocene (Nihowan) beds of Taiku, a modern looking fish, *Carassius auratus* was described by Chang (1933). In the upper Sanmenian (=Nihowan) series of Pinglu, southern Shansi, remains of *Ctenopharygodon* and *Hypophthalmichthys* were recorded by Bien (1934a). Those fish remains found in the lacustrine deposits

of the same age, Cyprinidae and other fishes, are chiefly represented by isolated vertebrae.

12. *The Pleistocene fishes.* The only known locality with fish remains of Pleistocene age is the Locality 3 of Choukoutien; these remains have been described by Bien as *Ctenopharynodon idellus* (1934).

GEOGRAPHICAL DISTRIBUTION.

On the accompanying map, I have plotted all the known localities with fossil fishes. This will give a general view of what we know about the fossil fishes in China. These localities are scattered widely throughout the vast country. It is, therefore, hoped that more localities will be found. As shown on the map, all the Palaeozoic fishes are restricted to south China, while all the fishes of later periods are much more widely distributed.

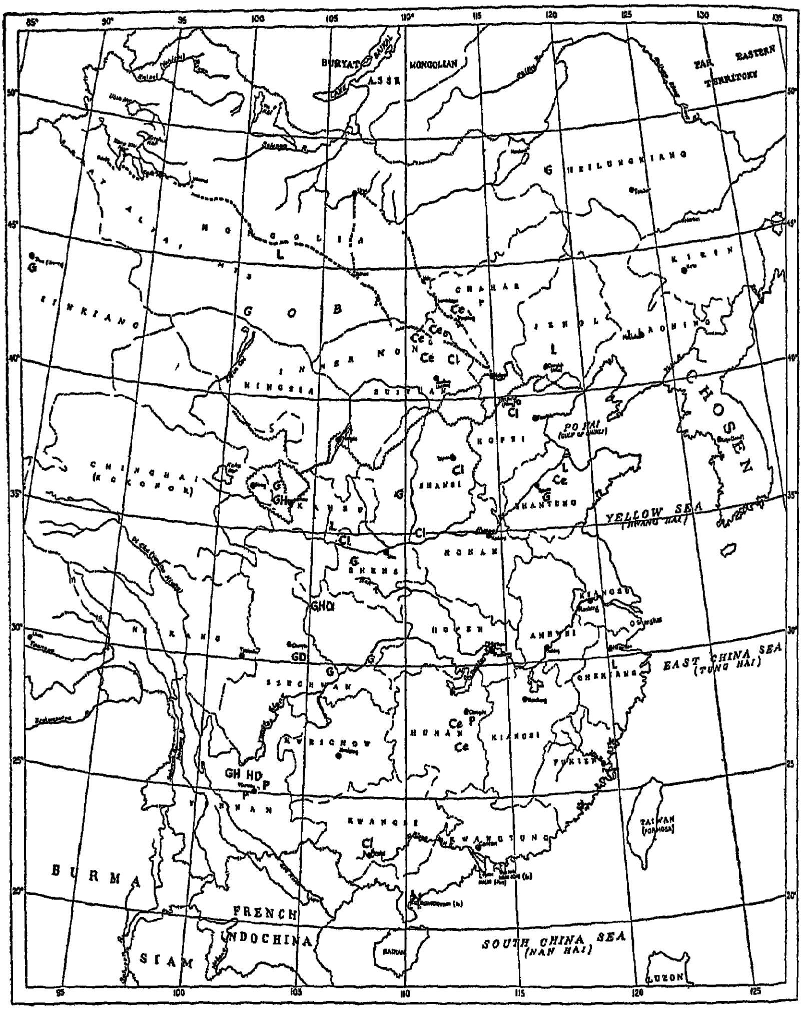
As I have mentioned above, most of the collections of fossil fishes are merely the by-products of other geological and palaeontological field explorations. With better understanding of the importance of the fossil fishes and by careful collecting, better specimens and new localities are surely going to be uncovered from time to time.

It is worth while to note that most of the fishes known in China are surprisingly similar to their equivalents in other countries. As examples I wish only to point out the close resemblance of *Bothriolepis sinensis* with *B. canadensis* and *Lepidotus* sp., with its equivalent of the Purbeck formation in England. Careful study of the fossil fishes of China will help us very much in a better understanding and correlation of the stratigraphy between China and other parts of the world.

5. SYSTEMATIC SUMMARY.

Up to now, as enumerated above, the following fishes are known in China:

- Osteostraci.
  - Cephalaspidae indet.
- Antiarchi
  - *Bothriolepis sinensis*
- Selachii.
  - Hybodontidae
  - *Hybodus houtienensis*
  - *Hybodus* sp.



General outline map of China showing the fossil fish-bearing districts in China P, Devonian fish localities; H, localities with *Hybodus;* D, localities with *Ceratodus,* G, Ganoid localities; L, localities with *Lycoptera;* Ce, localities with remains chiefly of Cyprinidae of the early Tertiary age; Cl, localities with chiefly Cyprinidae and Clupedae of the late Cenozoic age. For detailed explanation see the text. A few sites with fishes, west of Tihua, are omitted

Dipnoi.
  Ceratodontidae
    Ceratodus szechuanensis
    Ceratodus sp.
Ganoidei.
  Semionotidae
    Sinosemionotus urumchii
    Lepidotus sp. nov.
  Amiidae
    Sinamia zdanskyi
    Pappichthys mongoliensis
  Lycopteridae
    Lycoptera sinensis
    Lycoptera ferox
    Lycoptera sp.
Teleostei.
  Clupedae
    Mesoclupea showchangensis
    Mesoclupea globicephala
  Clupedae indet
  Cyprinidae
    Leuciscus miocenicus
    Barbus linchuensis
    Barbus scotti
    Barbus szechuanensis
    Barbus brevicephalus
    Pseudorasbora macrocephala
    Catostomus sp.
    Carassius aaratus
    Hypophthalmichthys sp.
    Ctenopharyngodon sp.
      etc. . . .

If we remember that before twenty years ago almost no fish remains were scientifically studied except *Lycoptera*, we can feel we have made good progress during the last two decades, but if we realize how few forms of the entire varied fish kingdom we have found up to now, we must say that we have only made a beginning. It is unnecessary to say that more work should be done to promote our knowledge of fishes in China.

6. CONCLUSIONS.

The above short account shows that we have now a better knowledge of the fish remains, especially those of the early horizons which are still mostly unknown, than when I attempted

to give a review of new vertebrate horizons in China eight years ago (1937). The discovery of the principal Paleozoic fishes was made since the outbreak of the war between China and Japan.

Concerning future prospects, it is sufficient to say that, just as with other vertebrate fossils, China is one of the most promising countries for fish remains. I wish only to note that in Kwangsi, Yunnan and Hunan the lower Paleozoic is partly developed as continental facies, so that we may hope to find more fish horizons in the Devonian as well as Silurian and older levels.

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THE STRATIGRAPHY OF THE INDEPENDENCE SHALE OF IOWA.

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PART II.

DEEP WELL RECORDS.

Another source of information about the stratigraphic position of the Independence shale is found in the deep well records of Iowa. Drilling samples have been taken from many of the wells and are now preserved in the files of the Iowa Geological Survey at Iowa City. During a study of the samples of one of them, W. H. Norton discovered Independence fossils which were submitted to the present writer for identification. The well is a city well of Shellsburg in Benton county, Iowa. The log of this well made from a personal study of the samples is as follows:

Depth	*Material*	*Formation and Age*
0–20	drift	Pleistocene
		Devonian
20–60	limestone, fossiliferous	Cedar Valley
60–80	shale, fossiliferous[37]	Independence
		Wapsipinicon
80–85	lithographic limestone	Davenport
85–100	dolomitic limestone, sugary	Spring Grove
100–125	limestone and blue shale	Kenwood
125–150	limestone, sublithographic	Otis
150–165	limestone, chert, shale at bottom	Coggon
160–200	dolomite	Silurian

Another well at Shellsburg shows the following section:

Depth	*Material*	*Formation and Age*
0–160	drift	Pleistocene
		Devonian
50–60	limestone	Cedar Valley
60–70	shale	Independence
70–180	limestone	Wapsipinicon

Other city wells in Benton county add to the weight of the evidence confirming the presence of shale below the Cedar Valley. The Garrison city well has this record:

[37] Fossils recovered include *Douvillina stookeyi* Stainbrook, *Strophonelloids deeringi* Stainbrook, *Douvillinaria variabilis* (Calvin), *Tentaculites*, and crinoid stem segments.

Depth	*Material*	*Formation and Age*
0–40	drift, etc.	Pleistocene
		Devonian
40–50	limestone	Cedar Valley
50–65	blue shale	Independence
		Wapsipinicon
65–70	limestone	Davenport
70–85	limestone	Spring Grove
85–90	limestone and shale	Kenwood
95–105	limestone	Otis

The well is in a valley in Cedar Valley limestone which is exposed for nearly its full thickness in the valley wall above the well curb. At Vinton, the Vinton Produce Company well yields this log:

Depth	*Material*	*Formation and Age*
0–70	drift	Pleistocene
		Devonian
70–150	limestone, fossiliferous	Cedar Valley
150–170	blue shale	Independence
		Wapsipinicon
170-175	limestone, lithographic	Davenport
175–200	dolomite	Spring Grove
200–220	limestone and shale	Kenwood
220–250	limestone, sublithographic	Otis
250–270	dolomite	Coggon
	dolomite	Silurian

The E. Wallace well is five and a half miles northeast of Vinton. The samples give this record:

Depth	*Material*	*Formation and Age*
90–150	limestone	Cedar Valley
150–160	blue shale	Independence
160–170	no sample	
170–225	limestone	Wapsipinicon

At Newhall a well has this log:

Depth	*Material*	*Formation and Age*
0–168	drift	Pleistocene
		Devonian
168–295	limestone	Cedar Valley
295–320	shale, crinoid segment	Independence
		Wapsipinicon
320-340	limestone, lithographic	Davenport
340–370	dolomite, sugary	Spring Grove
370–385		Kenwood
375–420		Otis
425–445		Coggon
445–470	dolomite	Silurian

At Atkins is a well yielding this record from a study of the samples:

Depth	*Material*	*Formation and Age*
78–83	drift	Pleistocene
		Devonian
83–200	limestone	Cedar Valley
200-210	shale	Independence
		Wapsipinicon
210–225	limestone, lithographic	Davenport
225–255	limestone	Spring Grove
255–270	limestone, blue shale	Kenwood
270–300	limestone	Otis
300–330	limestone and shale	Coggon
330–	dolomite	Silurian

A well at Watkins from the sample study shows this log:

Depth	*Material*	*Formation and Age*
		Mississippian
250–310	shale	Kinderhook
		Devonian
310–410	limestone	Cedar Valley
410–420	shale	Independence
		Wapsipinicon
420–425	limestone	Davenport
425–445	limestone	Spring Grove
445–455		Kenwood

Deep well at Van Horne:

Depth	*Material*	*Formation and Age*
0–155	drift	Pleistocene
		Devonian
155–247	shale	Unnamed
247–370	limestone, fossiliferous	Cedar Valley
370–420	shale, fossiliferous	Independence
420–460	limestone, dolomite	Wapsipinicon

In Linn county are a number of surface exposures of the shale. Near Center Point two deep wells have been drilled and the suites of samples from them show the presence of the shale below the Cedar Valley limestone.

A well at Center Point gives this section:

Depth	*Material*	*Formation and Age*
		Devonian
60–80	limestone	Cedar Valley
80–100	blue shale and sand	Independence
		Wapsipinicon

Depth	*Material*	*Formation and Age*
100–110	lithographic limestone	Davenport
110–130	limestone, brownish	Spring Grove
130–140	argillaceous limestone, shale	Kenwood
140–165	limestone, sublithographic	Otis
165–185	dolomite and limestone, buff	Coggon
		Silurian

The G. M. Mounce well (W 1028) near Center Point also shows in samples about thirty feet of shale and argillaceous limestone below the Cedar Valley and above Wapsipinicon. Crinoid segments and a fragment of an echinoid spine were recovered from shale at the depth of 98-106. Minute quartz crystals with doubly pyramidal ends are also common.

In Buchanan county the Independence shale was first seen and described. In the B. F. Nabholz farm well east of Brandon, argillaceous beds with sandstone occurs below the Cedar Valley. This well is about a mile east of the exposures of the shale northeast of Brandon.

At Charles City in Floyd county a well whose curb is on Cedar Valley limestone reveals this record:

Depth	*Material*	*Formation and Age*
		Devonian
1–100	limestone	Cedar Valley
100–120	shale	Cedar Valley
120–210	dolomite and limestone	Cedar Valley
210–220	silt, etc.	Independence
220–300	dolomite	Silurian

Farther south in Butler county at Clarkesville, the Henry Woods State Park well shows this log:

Depth	*Material*	*Formation and Age*
0–70	drift	Pleistocene
		Devonian
70–120	limestone	Cedar Valley
120–137	shale	Independence

In Johnson county the W. Fisher well near North Liberty shows:

Depth	*Material*	*Formation and Age*
0–130	loess and drift	Pleistocene
		Devonian
130–140	limestone	Cedar Valley
140–155	blue shale	Independence
		Wapsipinicon
155–170	limestone, white	Davenport
170–195	limestone	Spring Grove
195–205	limestone and shale	Kenwood

In Iowa county several deep well sample suites indicate the presence of shale below Cedar Valley limestone.

A well at Homestead has this log:

Depth	*Material*	*Formation and Age*
0–280	drift	Pleistocene
280–470	shale	Mississippian or Devonian
		Devonian
470–560	limestone, fossiliferous	Cedar Valley
560–575	shale	Independence
		Wapsipinicon
575–595	limestone, white	Davenport
595–600	(missing)	
600–620	dolomite	Spring Grove
(well continues)		

At South Amana the record is as follows:

Depth	*Material*	*Formation and Age*
0–210	drift	Pleistocene
210–300	shale	Mississippian or Devonian
		Devonian
300–375	limestone, fossiliferous	Cedar Valley
375–390	blue shale	Independence
		Wapsipinicon
390–405	lithographic limestone	Davenport
405–430	dolomite	Spring Grove
430–445	shale and limestone	Kenwood
445–460	limestone, lithographic	Otis
(record continues)		

The South Amana well is a few miles west of the one at Homestead but the records differ somewhat in the thicknesses of the formations penetrated. These variations are readily accounted for as there is a great unconformity between the Pleistocene and the Kinderhook shale and a large one between the shale and the Cedar Valley limestone. The thicknesses of the Devonian formations also differ slightly, as would be expected. Drilling samples at the tops and bottoms of adjacent formations show considerable mixture and the location of the boundary lines between is subject to an error of a few feet either way.

In the same county but farther west is the Marengo well which shows:

Depth	*Material*	*Formation and Age*
0–280	drift	Pleistocene
		Mississippian or Devonian
280–326	shale	Devonian
326–460	limestone	Cedar Valley
460–480	shale	Independence
480–515	limestone and dolomite	Wapsipinicon

These records, all derived from a study of the drilling samples of wells in the east central part of Iowa in the area of its surface exposures, reinforce the conclusion that the Independence shale occurs below the Cedar Valley limestone and above the Davenport member of the Wapsipinicon.

Southeast of that area in Iowa centering about the counties of Linn, Benton and Buchanan where most of the exposures of the shale occur, the Independence may be traced below the surface by deep well samples into Missouri. Study of the suite of samples from a well at Brighton, Washington county, Iowa, gives this record:

Depth	*Material*	*Formation and Age*
0–90	drift	Pleistocene
		Mississippian
90–370	limestone	Osage
370–650	shale	Kinderhook
		Devonian
650–790	limestone, fossiliferous	Cedar Valley
	sandstone at base of above	Independence
790–890	gypsum, limestone, chert, and dolomite	Wapsipinicon
		Ordovician
890–1000	shale	Maquoketa

At Mt. Pleasant in Henry county, Iowa, a well yields this log:

Depth	*Material*	*Formation and Age*
0–68	drift	Pleistocene
		Mississippian
68–234	limestone	Osage
234–602	shale	Kinderhook
		Devonian
602–729	limestone, fossiliferous	Cedar Valley
729–740	shale	Independence
740–806	limestone, gypsum, dolomite	Wapsipinicon
		Ordovician
806–848	shale	Maquoketa

A well at Letts in Louisa county, Iowa, has this sample record:

Depth	*Material*	*Formation and Age*
		Pleistocene
0–280	drift	
		Mississippian
280–325	shale	Kinderhook
		Devonian
325–440	limestone	Cedar Valley
440–446	sandstone	Independence
446–578	limestone, etc.	Wapsipinicon
		Ordovician
578–810	shale	Maquoketa

At Keokuk in Lee county, Iowa, the Hubinger well shows this driller's record:

Depth	*Material*	*Formation and Age*
		Pleistocene
0–20	drift	
		Mississippian
28–290	limestone, etc.	Osage
290–560	shale	Kinderhook
		Devonian
560–625	limestone	Cedar Valley
625–645	sandstone	Cedar Valley
645–700	limestone	Cedar Valley
700–737	sandstone	Independence
		Ordovician
737–800	shale	Maquoketa

From these sections it is noticeable that the Independence changes from shale to sandstone toward the southeast. Apparently this change in lithology indicates the approach to the land mass of the Ozark uplift. Stratigraphically the Independence corresponds to the 15 foot bed of sandstone which outcrops about ten miles south of Hannibal, Missouri. At this locality[38] the Callaway limestone has typical Cedar Valley fossils and the limestone below, the Cooper, is white, lithographic and in every way similar to the Davenport member of the Wapsipinicon. This sandstone[39] appears to be the same one previously designated as the Auxvasse Creek sandstone member of the Callaway and there seems to be little doubt that it is the continuation of the sandstone below Cedar Valley to the north in southeast Iowa and of the Independence shale farther north. In several places in Linn county, Iowa, the Independence has sandy phases or is nearly a sandstone.

[38] Guidebook, Fifteenth Annual Field Conference, Kansas Geol. Soc, 1941, p. 65.

[39] Counselman, F. B.: 1935?, Mo. Acad. Sci. Proc., vol. 1, pp. 105, 108-113, 119.

In northwestern Illinois the Hoing sandstone occupies the same stratigraphic position between the Cedar Valley limestone and the lithographic Davenport member of the Wapsipinicon. The Hoing is stated[40] to overlie unconformably the Wapsipinicon and to be everywhere overlain by Cedar Valley. Later Weller[41] states that the Hoing sand is the basal member of the Cedar Valley in the Colmar-Plymouth field of Illinois and present also in the Centralia-Salem area. The present writer believes that the Hoing sand of Illinois, the Auxvasse Creek sandstone member of Missouri and the sandstone and shale in Iowa are all region equivalents and are near-shore phases of the fossiliferous Independence shale farther northwest in central Iowa.

The Independence shale can also be traced below the surface in deep wells into Nebraska and northwest Missouri. At Nevada, in Story county, Iowa, the section as revealed by a study of drilling samples is as follows:

Depth	*Material*	*Formation and Age*
0–68		Pleistocene
68–260		Pennsylvanian
268–660		Mississippian
570–660	shale	Kinderhook
660–1210		Devonian
660–800	shale and limestone	Lime Creek
800–850	limestone	Shellrock
850–1000	limestone	Cedar Valley
1000-1010	limestone and sandstone	Independence
1010–1330	limestone, dolomite, gypsum	Wapsipinicon
1330–1920		Ordovician (Maquoketa to St Peter)

At Mitchellville in Polk county, Iowa, the section, summarized is:

Depth	*Material*	*Formation and Age*
0–85		Pleistocene
85–500		Pennsylvanian
500–670		Mississippian
505–670	shale	Kinderhook
670–875		Devonian
670-760	limestone	Cedar Valley
760–785	shale	Independence
785–875	limestone, dolomite, sandy at base	Wapsipinicon
(record continues)		

40 Weller, J. M: 1935, Personal communication, Guidebook, Kansas Geol. Soc., Ninth Annual Field Conference, p 259.

41 Weller, J. M: 1940, Devonian Correlations in Illinois and Surrounding States. a summary; Symposium on Devonian of Upper Mississippi Valley, Univ. of Illinois. In press

At Des Moines, in Polk county, Iowa, the section, with beds above and below omitted, is:

Depth	*Material*	*Formation and Age*
		Mississippian
765–770	blue shale	Kinderhook
		Devonian
770–915	limestone, some shale	Cedar Valley
915–930	limestone, shale, sandstone	Independence
935–1025	lithographic limestone. shale, anhydrite, dolomite, etc.	Wapsipinicon
(record continues)		

At Ogden in Boone county, Iowa, the section, with beds above and below omitted, is:

Depth	*Material*	*Formation and Age*
		Mississippian
620–630	shale	Kinderhook
		Devonian
630–750	limestone	Cedar Valley
750–760	shale	Independence
760–980	dolomite, limestone, etc	Wapsipinicon
(record continues)		

At Woodward in Dallas county, Iowa, a well yields this record of Devonian rocks:

Depth	*Material*	*Formation and Age*
		Mississippian
790–840	shale	Kinderhook
		Devonian
840–970	limestone	Cedar Valley
970–983	shale	Independence
983–1045	limestone, etc.	Wapsipinicon
(record continues)		

At Dexter in Dallas county, Iowa, a similar brief section derived from a study of well samples is:

Depth	*Material*	*Formation and Age*
		Mississippian
1020–1050	shale	Kinderhook
		Devonian
1050–1140	limestone	Cedar Valley
1140–1150	shale	Independence
1150-1230	limestone, dolomite, shale	Wapsipinicon
(record continues)		

At Stuart in Guthrie county, Iowa, a summarized section of a well is as follows:

Depth	*Material*	*Formation and Age*
		Mississippian
1177–1218	shale	Kinderhook
		Devonian
1218–1368	limestone	Cedar Valley
1368–1396	shale and limestone	Independence
1396–1690	limestone, gypsum, dolomite, shale	Wapsipinicon
(record continues)		

At Council Bluffs, in Pottawattomie county, Iowa, the Devonian section of a well is:

Depth	*Material*	*Formation and Age*
		Devonian
1160–1285	limestone	Cedar Valley
1285–1320	blue gray shale	Independence
1320–1500	limestone	Wapsipinicon

At Nebraska City, Nebraska, a shortened record of a well is:

Depth	*Material*	*Formation and Age*
		Mississippian
1220–1440	shale	Kinderhook
		Devonian
1440–1640	limestone, dolomite	Cedar Valley
1640–1665	shale	Independence
1665–1840	limestone, dolomite	Wapsipinicon

In a well in the northeast corner of Missouri in Buchanan county and in one near Tarkio, sandstone appears between the Cedar Valley (Callaway) and Davenport (Cooper) limestone equivalents.[42]

DISTURBED EXPOSURES OF THE INDEPENDENCE SHALE.

In a number of places Independence shale, bearing typical fossils and plainly distorted and disturbed, occurs adjacent to Cedar Valley limestone in evidently abnormal positions. With few exceptions, which are noted in the following paragraphs, all exposures of the shale show these features in common. In the first place the fossils found in most of the exposures of the disturbed shale are typical Independence forms identical with those collected from the formation in place below Cedar Valley limestone; in no place were Lime Creek species observed or collected therein. Secondly the shale generally abuts the Cedar Valley limestone on one side only. The plane between the

[42] Information from F. B Counselman

shale and the limestone is always sharp, nearly vertical and never passes beneath the shale. In the fourth place in no locality of the thirty odd known to the writer does the shale lie on Cedar Valley limestone in an erosion channel as an original deposit. Nor is the shale, as far as the writer could determine in the field, "supported" by the limestone as intimated by Cooper,[43] assuming that "support" means that the shale overlies the limestone. The shale has never been seen to lie on the Cedar Valley limestone in normally stratified layers as in the case of the State Quarry limestone. In Johnson county, Iowa, the concave erosional contact between the Cedar Valley and the State Quarry above it is readily apparent in several localities.

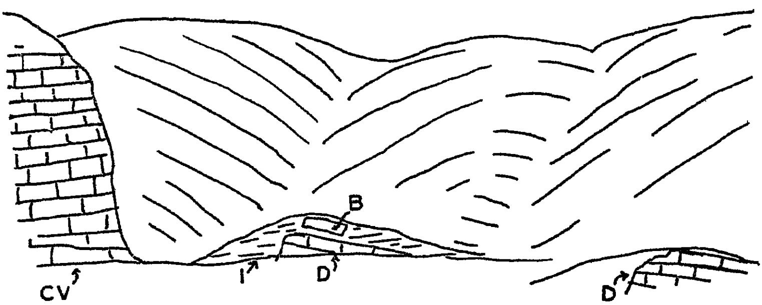

Fig 5 Diagrammatic view of fault conditions at south end of Lake Minne Estima, Benton county, Iowa. Davenport limestone is present with fossiliferous Independence shale above. Middle Cedar Valley beds are immediately adjacent to the north. I, Independence shale; C V, Cedar Valley limestone; D, Davenport limestone; B, block of basal Cedar Valley limestone.

Faulting, to the writer, best explains the abnormal position of the shale and is in accord with the conditions seen in the various exposures. The separation face between the shale and Cedar Valley limestone is the visible evidence of a fault plane and not of an erosion surface. The Cedar Valley formation where exposed is commonly faulted and buckled and shows considerable disturbance throughout its visible extent. Faults of a few feet throw are not uncommon.[44] The fossiliferous shale in known exposures is everywhere in contact with the lower strata of the Cedar Valley and in no place would the fault movement necessary to bring the shale up from immediately

[43] Cooper, G A.: 1942, Bull. Geol. Soc. Amer., vol 53, p 1766.
[44] Calvin, S 1898, Iowa Geol. Surv., vol. 9, p. 238.

below the limestone have been greater than 30 to 40 feet. Careful study by the present writer of the many disturbed exposures brought forth no evidence that faulting had not occurred or that the occurrences could be better explained in any other way.

In Benton county, Iowa, near the south end of lake Minne Estima in Harrison township, is an enlightening exposure of the shale. In the east wall of the valley of Cedar river is a forty foot cliff of Cedar Valley limestone comprising the layers from forty to eighty-five feet above the base of the formation. At the south end of the cliff the limestone ceases abruptly. To the south and perhaps twenty feet away and on the same level at the base of the cliff is a two-foot ledge of lithographic Davenport limestone dipping southward. A few yards farther south an abandoned quarry shows that the Davenport limestone is a few feet thicker. Above the Davenport limestone is Independence shale with its typical fossils. The Davenport beds are stratigraphically fifty feet or so below the limestone forming the base of the adjacent cliff section of Cedar Valley. The relations (see Fig. 5) can only be explained by faulting. Further support for this explanation is given by a large block of fossiliferous limestone lying on the shale and carrying species which are found only in the basalmost layers of the Cedar Valley. In the area there is no known exposure of the basal Cedar Valley beds closer than five or six miles. It seems apparent that this block of basal Cedar Valley limestone must have been moved upward in the movement that has brought the Davenport limestone and the superjacent Independence shale into juxtaposition with the middle layers of the Cedar Valley limestone. Appeal to downward movement into a cavern or sink hole as an explanation of the presence of the shale seems inapplicable here.

Several writers (Cooper, Stookey and Savage)[45] have stated their belief that the abnormal occurrences of the Independence shale described above are to be explained in another way; namely, that the shale occurs in sinkholes and caverns in the Cedar Valley limestone. Sinkholes filled with shale do occur in the Cedar Valley as at Moscow, Iowa, and elsewhere, and the deposits when revealed by quarry operations typically have an upward funnel-shape, which, however, is never seen in the exposures of disturbed Independence shale. The present writer has carefully sampled and sieved the shale in these sinkholes and has

[45] See historical summary above

never recovered a typical Independence fossil from them. At Moscow conodonts were found in the shale but they have a different aspect from those found in the Independence. The abundant carbonaceous remains, numerous plant fossils and general lack of marine fossils indicate that the shale sinkhole deposits at Moscow and elsewhere are continental and non-marine. The known near occurrences of Pennsylvanian shale and sandstone make it probable that these deposits in true sink-holes in the Cedar Valley are Pennsylvanian in age. This is all the more probable as the Mississippian period would afford sufficient time for sinkholes and channels to be formed by erosion into 100 to 150 feet of Cedar Valley limestone to the base of the formation. It is rather strange that the State Quarry limestone which does lie unconformably on the Cedar Valley does not occur in sinkholes therein. Near North Liberty in a well, shale is found in drilling samples below Cedar Valley in the near vicinity of an outcrop of State Quarry limestone.

Likewise it is difficult for the writer to believe that sinkholes formed during the uplift of a region would not, if open to the surface, be filled wholly or in part, by continental deposits, or that they could remain open until covered by an invading sea and then be filled with shale and limestone containing marine fossils. Probabilities would appear to be against this happening in most cases. How could it occur in dozens of places, widely scattered and distant from each other as are the exposures of disturbed Independence shale? To account for these known exposures the number of sinkholes and caverns must be exceptionally large as it is very probable that only a small fraction would be discovered in wells and quarries in a region so completely and thickly covered by Pleistocene deposits.

Secondly, the disturbed shale is always in contact with the lower layers of the Cedar Valley. If the shale occurred in sinkhole deposits surely some of them should be in the upper half of the formation. Such is not the case as thus far none has been observed.

Lastly, the shale in the exposures under discussion never occurs in continuous layers as originally deposited but is broken and distorted with pieces from several horizons intermingled. This condition could scarcely be the case if the shale were primarily deposited in sinkholes and caverns as indicated by the proponents of the sinkhole hypothesis. It is also inconceivable how the Independence could have been deposited in sinkholes in

the Cedar Valley limestone without debris from the walls and beds above being deposited or washed in simultaneously. The contact between the shale and limestone on fresh exposure is sharp, is not that of erosion and the shale, especially in undisturbed exposures, is remarkably free from erratic blocks of higher layers of the Cedar Valley. What few blocks of limestone are found in the shale are always from the basal layers of the Cedar Valley and not from the upper beds and have fallen onto the shale during erosion rather than having been originally incorporated during deposition. There is little evidence to support the hypothesis that the Independence shale occurs in sinkholes in the Cedar Valley as a primary deposit from above.

Proponents of the hypothesis that the Independence shale is younger than the Cedar Valley should explain whence the shale came downward into the limestone. Several (Stookey, Scobey and Savage)[46] have stated that the parent formation is the Lime Creek. That this is not the case is shown by a comparison of the macro-fossils from the two formations. This evidence is stated at length in another paper and need not be repeated here. It is sufficient to state that the faunas are so different as to be of different ages. Apparently recognizing this fact, Cooper,[47] and after him, Schuchert,[48] have interpolated this missing parent formation in between the Juniper Hill and Cerro Gordo members of the Lime Creek formation. There is no field evidence known to the present writer which supports this contention. The Cerro Gordo shale lies conformably on the Juniper Hill shale and deposition was continuous from the lower into the upper member. The scant fauna of the Juniper Hill shale shows little relationship with that of the Independence and contains no species to indicate its comparative age. The present writer has shown elsewhere that the faunas of the Cerro Gordo and the Independence shale are distinct and he did not find any evidence in them to show that the Cerro Gordo shale was immediately the younger in age. Faunally, then, there is no support for the supposition that there was once a formation, now wholly unknown, between the two lower members of the Lime Creek which was the source of the shale deposits known

[46] See historical résumé above

[47] Cooper, G A · 1942, Bull Geol Soc Amer, vol 53, p 1737 and chart.

[48] Schuchert, Charles: 1943, Stratigraphy of the Eastern and Central United States, p 700

as the Independence. Cooper[49] justifies this placing of the Independence shale by his assumption that the Independence fauna is of Chemung age. This assignment of the Independence fauna the present writer in his study does not find to be probable because of lack of many Independence species in the Chemung and vice versa. Since the Lime Creek does not appear to have been the source of the shale supposedly washed down into sinkholes near the base of the Cedar Valley, the downward movement of the Independence shale into the Cedar Valley and its younger age, therefore, can be regarded as unproven.

In several localities shale does occur in joints in the basal layers of the Cedar Valley formation. However these joints become narrower and disappear upward. These occurrences of the shale are homologous with the well known sandstone dikes[50, 51] which have been shown to have been formed by the upward movement of the sand. The Independence shale is typically soft and extremely plastic when wet. Since the Cedar Valley limestone is much jointed and occasionally faulted, there is no difficulty in explaining the presence of the shale in vertical crevices and cracks as due to upward movement induced by the weight of the Cedar Valley on a plastic shale directly beneath. The slight movements of ten to thirty feet necessary to account for the shale above its usual position does not appear improbable when one considers the upward thrust of hundreds of feet in salt domes and in the formation of the clastic dikes described by Diller and others. Norton[52] mentions the upward movement of red and green shales into the brecciated superjacent Monroe limestone on Mackinac Island. Trowbridge[53] states that often the Maquoketa shale similarly occurs above its expected situation in many places in the upper Mississippi valley. The peculiar Devonian deposit described by Weller[54] does not appear to have been formed in the same way as the Independence shale joint fillings. The wear suffered by some of the fish teeth in the former suggests also the possibility that they might have been introduced into their present situations as a secondary deposit during a subsequent period of erosion.

In one place evidence was observed that the Independence

[49] Cooper, G. A.: 1942, idem, Chart.
[50] Diller, J. S.: 1890, Bull Geol. Soc. Amer., vol. 1, pp 411-442.
[51] Parker, Ben H.: 1933, Jour Geol, vol 41, pp. 38-51.
[52] Norton, W. H.: 1920, Iowa Geol Surv, vol. 27, p. 396.
[53] Trowbridge, A C: 1940, personal communication.
[54] Weller, Stuart: 1899, Jour Geol., vol 7, pp. 483-488.

shale has moved upward into a large cavern or chamber in the Cedar Valley. On the Close farm two and a half miles southwest of Brandon, in Benton county, Iowa, a quarry, mainly in the Rapid member of the formation, has exposed a mass of blue-gray shale wholly enclosed at the sides and above by limestone. The bottom of the shale is not observable but apparently is below the limestone which surrounds it. The shale mass (Fig. 6) is broader at the base and decreases in diameter upward. In the shale typical macro- and micro-fossils of the Independence are present with numerous scattered and mixed blocks of harder shale and limestone. On fresh exposure, "flow

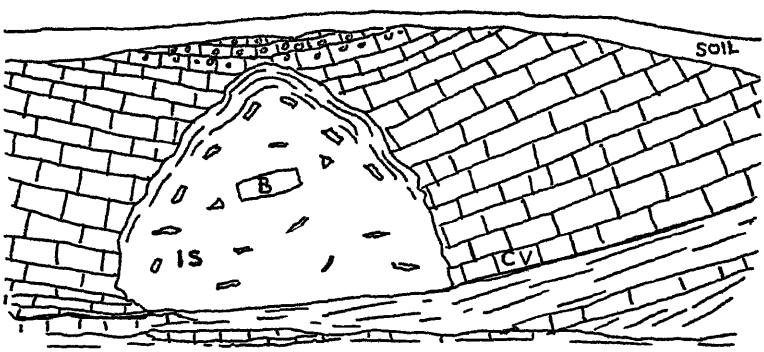

Fig 6. Diagrammatic section in quarry on Close farm, two and a half miles southwest of Brandon, Iowa The Independence shale fills a cavern in Cedar Valley limestone I S, Independence shale; C V, upper Cedar Valley; B, block of basal Cedar Valley limestone, about 30 feet above normal position The lines near the ceiling represent "flow lines."

lines" are visible in the shale parallel to the enclosing walls. That these lines are not stratification laminae was apparent as the lines curved upward so as to be roughly parallel to the lateral and upper limestone walls. Also blocks of hard shale of variable lithology were roughly aligned similarly but true bedding planes were absent. The mass consisted of thoroughly broken and mixed shale. This deposit of shale is totally at variance with deposits of Pennsylvanian age in caverns in the Cedar Valley near Rock Island, Illinois, and described by Hall.[55] Furthermore, the base of the shale mass on the Close farm is surrounded by the basal beds of the Rapid member which are about

[55] Hall, James: 1858, Geol. of Iowa, vol. 1, part 1, p. 130.

thirty feet above the base of the Cedar Valley. In the shale were several specimens of *Atrypa cf. independensis* Webster, a species typical of the basalmost layers of the Cedar Valley. Also midway in the shale is a block of limestone, 2′ x 3′ x 1′, which also carries examples of the same *Atrypa*. It seems beyond the bounds of probability that any agent could have deposited in a sinkhole from above, a block of limestone from beds stratigraphically thirty feet below and not outcropping within miles of the place. The upward movement of the plastic Independence shale from directly below the Cedar Valley readily explains the features seen in this occurrence of the shale. The chamber now filled with shale could have been formed at any time during the long interval since the close of the Devonian by the solvent action of ground water. The insoluble shale would limit the downward solution of the cavity while the weight of the 150 feet of superjacent limestone would be sufficient to supply the motile force. Exposure No. 3, described by Thomas and Norton,[56] seems to be a similar deposit but in this instance has been exposed to view by the erosive work of the Cedar River.

In summary it is found that in most of the exposures where the shale is not in normal position that all available evidence points to faulting as the true explanation of the abnormality. No deposit of Independence shale has as yet been seen to lie in erosional depressions and channels on the Cedar Valley limestone. The hypothesis that the Independence shale has come down from above into caverns and erosional crevices in the Cedar Valley is untenable: a later shale formation, the Lime Creek, as shown by faunal studies could not have been the parent formation; the Sheffield shale could not have supplied the shale either as its fauna is totally unlike that of the Independence; there is no field evidence of a shale body which could have been the source as supposed by Cooper and Schuchert to have been present between the Juniper Hill and Cerro Gordo members of the Lime Creek. In the one known occurrence of the Independence shale in a cavern in the Cedar Valley, all evidence points to its movement *upward* into its present position. The hypothesis that the Independence shale is a mass of material that has moved downward into the Cedar Valley may well be abandoned. On the other hand the source body of shale is seen in the field to be present below the Cedar Valley.

[56] See historical résumé above.

LITHOLOGY AND THICKNESS.

The Independence is typically a blue-gray calcareous shale. It is highly plastic when wet and breaks down on exposure into a structureless clay. Locally beds of one to two foot thickness may be more strongly impregnated with calcareous material and form layers of argillaceous limestone at Brandon. Often the shale has black layers because of the abundance of carbonaceous material. In some areas the carbon content is high enough that thin beds of impure coal up to an inch in thickness were formed. It is this coal-like substance which, encountered in wells passing through the Cedar Valley limestone, induced futile and expensive attempts to obtain coal in the Devonian by sinking shafts. Pyrite in cubical crystals and twinned masses is also common and locally encrusts many of the fossil shells.

In a few instances the Independence may have sandy layers as at several localities in Linn county, Iowa. This sandy phase is often encountered in wells and when traced southward the Independence changes wholly to a sandstone in northwestern Illinois and in northwest Missouri.

At the type locality near Independence, the shale was about twenty feet thick. It was also penetrated nearly to this depth near Palo, Iowa. As well samples are generally obtained at five or ten foot intervals, well logs rarely give the full thickness correctly. In general the shale varies in thickness from ten to twenty feet, and rarely may be more in some localities.

DISTRIBUTION.

The surface exposures of the Independence shale are chiefly in Buchanan, Benton and Linn counties with one large exposure in Linn county. In these counties the shale occurs but a short way below the surface as the surface slope and the dip of the beds are about the same over a considerable area. Streams, then, do not have to cut deeply to reach the shale. The areas where the shale is exposed are not large and the outcrops are not continuous except for short distances. However continuous outcrops of the shale are hardly to be expected in a region with a heavy drift cover, especially if the formation is thin, easily eroded and quickly overgrown by vegetation. The outcrop, too, coincides in great part with the divide between the Wapsipinicon river and Buffalo creek which is covered with thick Pleistocene deposits. These have not been trenched by streams

deeply enough to reveal the shale below. Consequently no continuous area of the Independence is exposed or mappable. Similarly the eastern border of the Cedar Valley is deeply covered and can only be conjectured in most places and indefinitely indicated on geologic maps of the state.

The Independence shale is shown by deep well samples and shallow well records to be present in much of the area where Cedar Valley limestone is the bed rock. It extends from Osage and Charles City in Iowa southward to Keokuk and thence into Missouri where it appears at the surface near Hannibal as a sandstone Subsurface in northeastern Illinois the shale appears to be a sandstone also. Locally in Iowa the Independence shale may be absent, as in a small area north of Vinton, Iowa, and the area from Iowa City southeastward to Davenport. Westward the shale may be traced in deep wells to Council Bluffs, Iowa, and then into Nebraska and northwestern Missouri. (See Fig. 5.)

As Cooper and Warthin[57] indicate the surface occurrences of the Independence are "spotty" but these with the well records and artificial exposures are sufficient to demonstrate that the shale has a widespread distribution which precludes any explanation of the shale as a series of cave and crevice filling from above. It appears to the present writer highly improbable that the great number of caves demanded by this hypothesis would be developed over so wide an area in Iowa, eastern Nebraska, northern Missouri and northwest Illinois and all stratigraphically between the Cedar Valley and Wapsipinicon limestones.

CONCLUSIONS.

It has been shown that the Independence shale is a distinct formation and that in a number of exposures it lies in normal position immediately below the Cedar Valley limestone. Artificial excavations, as quarries and exploration shafts, similarly show that the shale occurs in the same stratigraphic position with the same fossils. Records from shallow wells, scattered over a number of counties, also demonstrate that a shale is present below the Cedar Valley in many localities. Numerous suites of drilling samples from deep wells over a wide area add the weight of their evidence in showing that shale is below the

[57] Cooper, G. A., and Warthin, A. S.: 1942, Bull. Geol Soc. Amer., vol. 53, p. 1766.

Cedra Valley. In the samples from deep wells at Shellsburg, Van Horn, and Center Point, Iowa, typical Independence fossils were recovered from shale immediately below that formation. The occurrence of shale masses in abnormal positions abutting Cedar Valley limestone is best and adequately explained by faulting. No evidence of downward movement of the Independence is seen in the field. On the contrary in at least one exposure, the shale evidently moved upward some thirty feet into a chamber. Shale in joints and crevices from field evidence has been thrust or moved upward.

Surface outcrops, artificial exposures, and deep and shallow well records indicate that the Independence shale is widespread in central Iowa and that it can be traced as a subsurface formation westward to Nebraska and southward into northern Missouri and northwestern Illinois. It has the same position stratigraphically in Iowa as a sandstone that lies between the Cedar Valley and Wapsipinicon in Illinois and one that in Missouri occurs between the Callaway and Cooper limestones.

That the stratigraphic position of the Independence shale is below Cedar Valley and above the Wapsipinicon may be regarded as demonstrated. From this it follows that, as the Independence by its fossils is lower Upper Devonian, the strata which lie above must be younger. The Cedar Valley limestone, the Shellrock formation and the Lime Creek beds are, then, Upper Devonian in age and post-Independence.

ADDENDA.

At Amana, Iowa, occurs a shale discovered by Dr. S. W. Stookey. Fossils collected by him were submitted to the writer who considered them to be closely akin to species in the Independence shale. Extensive collections were made later by the present writer and comparison with the Lime Creek fauna and that of the Independence shale showed that they were more nearly related to the latter although there were varietal differences and many significant absences.

In a paper on the brachiopods of the High Point sandstone of New York,[58] the writer made no distinction between the faunas of the Independence and that of the Amana beds because of their resemblances. It was suggested (p. 889) that the High Point fauna might be intermediate between the Lime

[58] Stainbrook, M. A.: 1942, Amer. Jour. Sci., vol. 240, pp. 879-890

Creek and the Independence. Faunal comparison showed that there were a number of species in common in the High Point and Amana faunas. Lately (1944) new deep wells in southern Benton county, Iowa, show that the Amana beds lie on Cedar Valley and therefore are younger than the true Independence and probably older than the Lime Creek. The relation of the Amana beds with the Lime Creek and other Devonian formations which lie on the Cedar Valley is yet to be worked out. It must be done wholly by well samples and records. The difficulty of correlating the High Point with either the Independence or the Lime Creek is removed as the Amana beds are its correlative in Iowa.

Thus a fossiliferous shale overlies the Cedar Valley limestone and another lies below it in Benton county. A recent well near Van Horne, Iowa, shows both shales separated by one hundred and twenty-seven feet of Cedar Valley.

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Lubbock, Texas

TWO CEPHALOPODS AND ARTHROPODS FROM THE WHITEHEAD FORMATION.

CECIL H. KINDLE.

ABSTRACT. Two species of *Apsidoceras* and an *Eoharpes* are newly recorded from the Whitehead formation. One is identical with and the others closely correlated with species from the Upper Ordovician of Anticosti Island Also illustrated is an eye larger than that of any known trilobite The exact nature of its owner is unknown

THIS paper makes known in the Upper Ordovician rocks of Percé the presence of four additional species. They have been in the writer's possession for some time. Publication has been delayed in the hope of getting more and better specimens, for half a specimen can be very tantalizing. In the *Eoharpes* only an impression of the central portion of the head is preserved, and the broken large arthropod eye stirs one to find more of that animal. In 1943 while making a final short collecting trip for Upper Cambrian fossils in the area a half day was spent at the Grande Coupe with these things in mind. Nothing worth bringing home was obtained however. What a contrast to a previous trip when the writer lost his balance when climbing the west side of the Grande Coupe with a heavy load of fossils on his back. A nasty fall was averted when his left hand came in contact with the specimen here described as *Apsidoceras milesi* firmly embedded under a rock ledge.

The lack of new specimens and an awareness on recently reading Flower's paper that some persons doubt the Upper Ordovician age of these rocks make publication now desirable. In addition to the specimens mentioned I find I have Billings' *Apsidoceras magnificum* which he described from the Ordovician of Anticosti Island.

A good summary of the species in the genus *Apsidoceras* is given by Flower and also of the genera in the Apsidoceratidae. The species found by G. Winston Sinclair and described by Flower has a much rounder cross-section than typical members of the genus. In this respect it is primitive, resembling the round cross-section of their ancestors. From the evolutionary point of view the presence of *A. montrealense* in the Trenton of Montreal indicates that the Whitehead formation, containing later types of *Apsidoceras*, is younger than the Trenton.

The specimens described here all came from the Grande Coupe exposures of the Whitehead formation and are in the writer's private collection.

Apsidoceras magnificum (Billings)

Gyroceras (Lituites) magnificum Billings, 1857. Geol. Surv Can, Rept. of Progress, 1853-1856, p. 307.
Lituites ? magnificum Billings, 1866. Cat. Sil. Foss. Anticosti, p. 23
Apsidoceras magnificum Hyatt, 1883. Proc. Boston Soc Nat. Hist, Vol 22, p 289.
Apsidoceras magnificum Foerste, 1927 Can. Geol Surv Mem 154, p. 280
Apsidoceras magnificum Foerste, 1928. Roy Soc. Can, Vol. 22, Sect 4, p. 223, Pl. 8, Figs 1, 2, Pl. 9, Fig. 1, Pl. 11, Fig. 6

One specimen of *Apsidoceras* in the collection agrees well with Foerste's description of *A. magnificum* given in Twenhofel's "Geology of Anticosti Island," p. 281. "The ventral side is almost flat, and the lateral and dorsal sides form an almost even curve including slightly more than half of a circle. Five and a half cameræ occur in a length equal to the lateral diameter. The sutures of the septa form broad, ventral lobes, angular ventrolateral saddles, and distinct dorso-lateral lobes, but the dorsal saddles are relatively broad and prominent. The depth of concavity of the septa [on the ventral side] equals the height of one of the cameræ."

No siphuncle is preserved in the specimen. The length is three and one half inches. The lateral diameter is 48 mm. and the dorso-ventral diameter is 33 mm.

Apsidoceras milesi, new species

Plate 1, Figs 1-5

Apsidoceras sp. Foerste, 1936. Jour. Pal, Vol 10, p. 379, Pl. 56, Fig. 8.

This is a large specimen and it must be borne in mind that the illustrations are one-half natural size. Foerste's illustration is of a fragment showing only the ventro-lateral saddles.

The lateral diameter is 74 mm. and the dorsal-ventral diameter is 50 mm. These proportions are the same as in *A. magnificum* but the latter seems more rounded. *A. milesi* is readily distinguished by its more concave ventral lobe of the suture and the angular dorsal saddle. About seven cameræ occur on the side in a distance equal to the lateral diameter. This distinguishes it from *A. magnificum multicameratum* Foerste in which 12 cameræ occur in the same distance. The previously described species from the Whitehead formation, *A. depressum*

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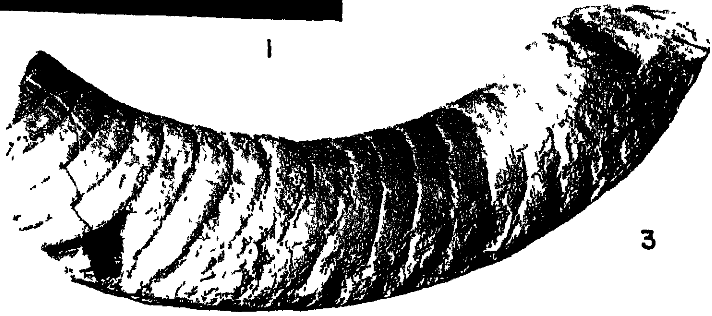

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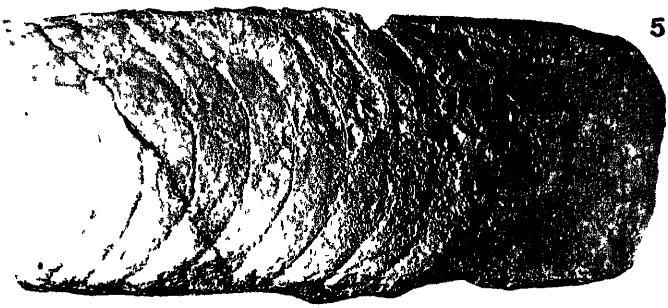
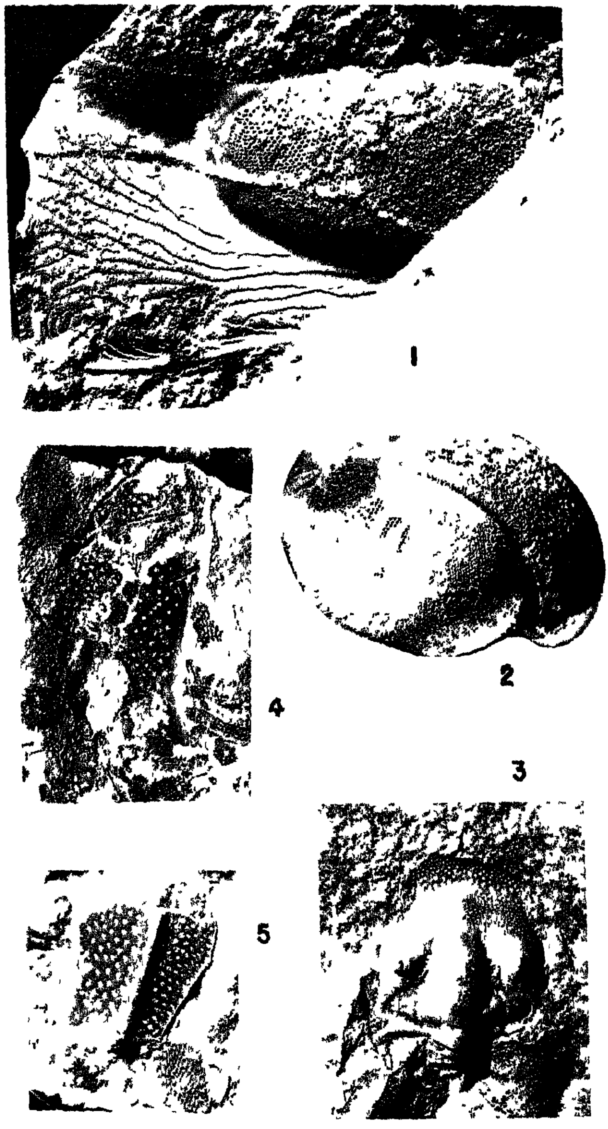


5

Apsidoceras milesi, new species All figures x ½. Fig. 1, anterior view; 2, posterior view, ventral surface partly crushed;



(All figures x 2½)

Fig. 1 Large arthropod eye
Fig 2 *Cyclopyge prisca* (Barrande) from Bohemia for comparison with fig 1
Fig 3 *Eoharpes percensis*, new species
Fig 4, 5 Portions of brim of *Eoharpes percensis?*

Cooper, differs in lacking a flat ventral surface and a dorsal saddle.

The species is named for Arthur Miles, photoengraver and for many years artist with the Geological Survey of Canada. After his retirement he continued to take an active interest in photographic methods. The writer has benefited greatly from discussions and experiments in fossil photography conducted in Mr. Miles' suburban home near the Ottawa river.

Eoharpes percensis, new species
Plate 2, Fig. 3

The only specimen known is an impression in limestone. It is perfect enough to show the main portion of the head but practically all the brim is missing. Parts of the brim may be represented by Figs. 4 and 5. *Eoharpes percensis* is quite different from *E. ottawaensis* in that it has no eye-line and has an elongated eye rather than a round one. Moreover the depressed area of the cheek near the posterior third of the glabella extends out more at right angles to the glabella than it is shown to do in illustrations of *E. ottawaensis*. From the Ordovician of Anticosti Island Twenhofel described *E. ottawaensis anticostiensis* on the basis of a difference in the brim ornamentation. His Fig. 2, Plate 61, however, shows a head which while lacking a glabella, yet more closely agrees with *E. percensis* than with *E. ottawaensis* and it is doubtful whether it should be regarded as a variety of the latter. The possibility exists that when better specimens are found from both the Whitehead formation and the Anticosti Ordovician they may prove to be the same species.

Large Arthropod Eye
Plate 2, Fig. 1

This large eye, like the *Eoharpes*, is an impression in limestone. The length of the preserved incomplete eye is 18 mm. The largest trilobite eye which has been described is that of *Cyclopyge prisca* (Barrande). For comparison a specimen of this trilobite is shown on Plate 2, Fig. 2. It is in the study collections at the City College and originally came from Sarka, Bohemia. Since *Cyclopyge* occurs in the Whitehead formation one's first guess is that here we have an extra large species of

this genus. But the cheek attached to the eye of *Cyclopyge* is very narrow, while this is wide and curiously ornamented. If it does belong to a trilobite, it is to a member of a new genus.

Other arthropods which have large eyes are the eurypterids. Clarke and Ruedemann illustrate *Pterygotus buffaloensis* which seems to have a compound eye over 10 cm. long. The surface markings on the heads of eurypterids illustrated in Clarke and Ruedemann's memoir are not similar to the markings on the "free cheek" of this specimen. Yet the possibility exists that this eye belongs, as the size indicates, to a eurypterid.

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SCIENTIFIC INTELLIGENCE

CHEMISTRY.

Outline of the Amino Acids and Proteins; edited by MELVILLE SAHYUN. Foreword by CARL L. A. SCHMIDT. Pp. 251, many figs. New York, 1944 (Reinhold Pub. Corp., $4.00).—This book is intended to provide a brief statement of the fundamental chemistry of the amino acids and proteins and of their metabolism in the animal body. It should prove useful to beginning students in biochemistry or physiology, or to those unable, for one or another reason, to undertake the study of the more detailed and difficult handbooks or of the original literature. It fills the gap between the treatment of the subject offered in the chapters on amino acids and proteins in the average textbook on biochemistry and that in specialized monographs. If employed as a class-room text and supplemented by lectures and demonstrations, it would doubtless form the basis of a satisfactory elementary course.

The authorship of the several chapters and their subjects are as follows: (1) Discovery of the Amino Acids by Melville Sahyun, (2) Proteins: Occurrence, Amino Acid Content and Properties by Carl L. A. Schmidt, (3) Protein Structure by Henry B. Bull, (4) Hydrolysis of Proteins by Melville Sahyun, (5) Synthesis and Isolation of Certain Amino Acids by Herbert E. Carter and Irving R. Hooper, (6) Methods of Analysis for Amino Acids and Proteins by David M. Greenberg, (7) Relation of Amino Acids and Their Derivatives to Immunity by Michael Heidelberger, (8) Relation of Amino Acids to Biologically Important Products and the Role of Certain Amino Acids in Detoxication by Armand J. Quick, (9) Metabolism of Proteins and Amino Acids by William M. Cahill, (10) Intermediary Metabolism of Individual Amino Acids by William M. Cahill, (11) Nitrogen Equilibrium and the Biological Value of Protein by William M. Cahill and Arthur H. Smith, (12) Amino Acids and Proteins in Nutrition by Madelyn Womack and Charles F. Kade. In addition a list of U. S. patents on amino acids and related compounds has been compiled by Dean Laurence and is given as an appendix.

The selection of material and organization of the presentation in most of the chapters is sound. The authors were clearly embarrassed by space limitations in their choice of what to put in and what to omit, but have made a praiseworthy effort to avoid superficial and oversimplified discussions. On the other hand, the book contains far more erroneous statements and infelicitous, not to say misleading, expressions than one could wish for. To men-

tion only a few of the former, it is startling to find that Scheele is supposed to have worked on malic acid in 1793 (p. 18), seven years after his death, and it is inaccurate to state (p. 89) that lysine is dismuted by alkali. Few investigators appear to realize that all amino acids, whether mono-amino, basic, or acidic, are more or less effectively extracted from aqueous solution by butyl alcohol provided the aqueous phase is maintained close to the isoelectric point of the amino acid under study. Thus the categorical statement that basic and acidic amino acids are not so extracted (p. 108) is misleading without further explanation. It is to be hoped that the statement that amino acid esters are, in Fischer's method, distilled with steam (p. 132) is nothing more than a slip of the pen, but the omission of isoleucine from the list of amino acids the copper salts of which are extracted by methyl alcohol (p. 133) is difficult to understand, in view of the manner in which this amino acid was first purified. This is described in an earlier chapter (p. 32).

In another category is the statement regarding the mechanism of the reactions employed for the determination of aspartic acid (p. 139) by bromination and oxidation after its conversion to malic acid by deamination. The text implies that the originators of this method suppose that the malic acid is brominated to dibromomalic acid which is then oxidized with permanganate to dibromo-oxaloacetic acid The product of the reaction is distilled with steam and determined with the aid of dinitrophenylhydrazine. The facts are that neither of the dibromo-acids mentioned is recorded in Beilstein and it is doubtful if either has ever been prepared. One would not expect in any case that this bromination would be a quantitative reaction suitable for analytical application. Furthermore, oxaloacetic acid does not yield a colored derivative when treated in the manner described for the determination of malic acid, and the authors of the paper specifically refrained from making any statement whatever regarding the mechanism of this still unexplained reaction.

Notwithstanding these and a number of other faults, the book can be recommended for the use of those who require only an outline type of treatment. Several of the chapters, especially those on synthesis and on metabolism are of outstanding excellence.

H. B. VICKERY.

Colloid Chemistry. Theoretical and Applied. Vol. V. *Theory* and *Methods. Biology* and *Medicine.* Edited by JEROME ALEXANDER. Pp. vi, 1256; profusely illustrated. New York, 1944 (Reinhold Publishing Corp., $20.00).—This book supplements Volumes I and II, published in 1926 and 1928 respectively. During this period of some eighteen years many important tools have been

developed: electron diffraction, the electron microscope, sonic and ultrasonic waves, high vacuum distillation, the cyclotron, and the betatron, all discussed in the first section of this book. There also are reviews of important advances in electrophoresis, centrifuges, film balances, and X-ray methods. And progress in theoretical domains has not been lacking; for this volume includes reviews of recent developments in the theories of polymerization, rheology, photographic development, elasticity of rubber, and the vitreous state.

The thirty-five papers in the second section devoted to biology and medicine cover such diverse topics as photosynthesis, starch chemistry, enzymes, vitamins, hormones, viruses, genes, protoplasm, capillary circulation, inflammation, blood coagulation, immunology, allergy, homeostasis, cancer, gerontology, aero-emphysema and caisson disease, infective aerosols, and psychiatry.

The editor has again enlisted the aid of recognized authorities, although in contrast with previous volumes, most of the contributors are now, of necessity, Americans. It cannot be said that the treatment of all of these subjects is uniformly good or equally comprehensive. This volume, like the previous ones (see Amer. Jour. Sci., Vol. (5) XII. p. 535, Dec., 1926; Vol. (5) XVIII: p. 164, August, 1929), is characterized by unevenness of style and lack of organization. This heterogeneity is favored by the editor because "the wide variety of topics considered in this series, and the different modes of approach to the same or interrelated subjects, will, it is hoped, give the user of the books a broader and more integrated view of natural phenomena than is obtainable from treatises of more limited scope." Certainly this approach is often impressive and stimulating, but it is doubtful if the average reader will obtain an integrated view of colloid chemistry from these books. E. J. KING.

GEOLOGY AND PALEONTOLOGY.

Volcanoes of the Three Sisters Region, Oregon Cascades, by HOWELL WILLIAMS. University of California Publications, Bulletin of the Department of Geological Sciences, Vol. 27, No. 3, pp. 37-84, 1944. Pls. 9, 4 figs., 1 map —This attractive paper adds another to Doctor Williams' growing list of descriptive and interpretative contributions on igneous geology in the Pacific region of the United States. The area considered in the paper lies in the High Cascades of west-central Oregon, and measures about 22½ miles north-south by 16½ miles east-west. A geologic map, on a scale of about 0.43 inch per mile, depicts 13 units of volcanic rocks. The oldest and most extensive unit consists of basaltic lavas which were erupted in the form of shield volcanoes during the Pliocene epoch. These older cones have been greatly dissected, especially by glacial

classification of the foraminifera. The trilobites, on the contrary, are arranged on a chronologic basis, all genera of Lower and Middle Cambrian being presented in the first group, those of the Upper Cambrian in the next, etc., and within each of these groups the arrangement is alphabetical.

Rarely a confused statement appears, as in the definition of the class Schizocoralla, in which it is said "main function of these plates [septum-like plates arranged around the periphery] is to provide asexual reproduction through simple fission of each corallite into two, three, or four corallites." Such plates, of course, could not be a *cause* but rather a *result* of fission. But on the whole the statements are clear, concise, and remarkably free of errors.

Index Fossils will be indispensable in every paleontological laboratory and will be useful in many ways in teaching paleontology. Paleontologists everywhere will be grateful for the years of careful and patient labor which Doctors Shimer and Shrock and their collaborators have devoted to this great work.

CARL O. DUNBAR.

PUBLICATIONS RECENTLY RECEIVED.

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American Journal of Science

APRIL 1945

CEPHALASPIDS FROM THE UPPER SILURIAN OF OESEL, WITH A DISCUSSION OF CEPHALASPID GENERA.*

GEORGE M. ROBERTSON.

ABSTRACT. The Cephalaspidae of the Middle Ludlow, Upper Silurian of Oesel are described They are *Thyestes verrucosus* Eichwald, *Witaaspis schrenckii* (Pander), *Witaaspis patteni* Robertson, *Saaremaaspis mickwitzii* (Rohon), and *Cephalaspis oeselensis* Robertson. *Eukeraspis pustulifera* Rohon is not identifiable

The basis for familial, generic, and specific categories in the Osteostraci is discussed. *Didymaspis* is raised to familial rank. A classification of the Osteostraci is given.

THE Upper Silurian deposits of the Island of Oesel, if they are correctly placed stratigraphically, are of Middle Ludlow or in part of Lower Ludlow age, and somewhat older than other Ostracoderm-bearing formations of the Upper Silurian. The wide deployment of Osteostraci at this period seems to indicate an emergence of the order at least as far back as the Ordovician, although no fossils which can be definitely identified as Osteostraci have been recovered from deposits earlier then this Lower to Middle Ludlow horizon. The Ordovician Ostracoderms thus far known are very fragmentary but seem to belong to the Heterostraci(1).

During the past ten years I have been working through the collection which the late Dr. William Patten had made, and from time to time have described various of the Osteostraci of Oesel from that collection. That survey has resulted in the erection of two new families, Dartmuthiidae and Oeselaspidae, five new genera, *Dartmuthia, Oeselaspis, Saaremaaspis, Rotsikullaspis,* and *Witaaspis*, and a number of new species, as well as redescription of several previously known species, especially of *Trematáspis*. The survey of the Osteostraci from that

* Contribution No. 49 of the Department of Zoology, Ft. Hays, Kansas State College.

collection is now completed unless future work on morphological problems discloses grounds for splitting off other groups from those at present regarded as single. It seems appropriate at this time, at the conclusion of the taxonomic account, to discuss the principles involved and the basis of establishing the various categories represented.

Three "cephalaspids" were described from Oesel by earlier workers. These are *Thyestes verrucosus* Eichwald(2), *Cephalaspis schrenckii* Pander(3), and fragments attributed by Rohon to *Eukeraspis pustulifera* Agassiz(4).

Cephalaspis schrenckii has been removed from the genus *Cephalaspis* and redescribed as *Witaaspis schrenckii*(5). A second species of this genus has been described as *Witaaspis patteni*(6). Other cephalaspids described from Oesel have been *Saaremaaspis mickwitzi*(7), earlier described by Rohon(4) as *Tremataspis mickwitzi*, and *Cephalaspis oeselensis*(8). The fragments identified as *Eukeraspis pustulifera* by Rohon, too incompletely known to be identified with any certainty, possibly pertain to *Cephalaspis oeselensis*. I do not feel sufficiently sure of the fragments to attempt their placement.

These species are briefly described as follows:

Thyestes verrucosus Eichwald.

1854 *Thyestes verrucosus* Eichwald (2) p. 108-110. Pl. II, fig 1.
1856 *Cephalaspis verrucosus* Pander (3) p.44-47. Pl. IV, figs. 1, 3, 4, 5, 6, 7.
1858 *Cephalaspis verrucosus* Huxley (9) p. 269.
1858 *Cephalaspis verrucosus* Schmidt (10) p 170, 184.
1860 *Thyestes verrucosus* Eichwald (11) p. 1532.
1866 *Thyestes verrucosus* Schmidt (12) p. 225-233. Pl. IV, figs. 1-11
1891 *Auchenaspis verrucosa* Smith Woodward (13) p 198.
1892 *Thyestes verrucosus* Rohon (4) p. 15-37, 86-87. Pl. I, figs. 1-10; Pl. II, figs. 1-6.
1892 *Thyestes verrucosus* Schmidt (14) p. 98.
1894 *Thyestes verrucosus* Rohon (15) p. 209. Pl. I, figs. 10-11.
1895 *Thyestes verrucosus* Rohon (16) Pl. II, fig. 6.
1899 *Thyestes verrucosus* Rohon (17) p. 6, fig 1.
1903 *Thyestes verrucosus* Patten (18).
1912 *Thyestes verrucosus* Patten (19) fig. 235.
1932 *Thyestes verrucosus* Stensio (20) p. 164-165.
1932 *Thyestes verrucosus* Smith Woodward (21).
1940 *Thyestes verrucosus* Robertson (22) p. 469, Pl. I, fig. 1.

Thyestes verrucosus is a small cephalaspid, the shield being about 20-22 mm. long, about 22-26 mm. broad at the level of the pectoral sinuses. The width varies considerably with the degree of compression. The cornua are short and broad. The distance from the rostral angle of the shield to the cornu tip is 5-7 times the length of the cornu. The length of the cornu is about 1 5 times its width at the base. The nasohypophysial fossa is wide and deep, with the short, wide aperture on a prominent longitudinal ridge in the fossa. The orbits are of medium size, about 3×2 mm, and oval in form. The sclerotic has never been described, but in some notes left by Doctor Patten is a sketch of a specimen which he ground down, and this sketch shows what he has labelled an "eye stalk" within the orbit. This I take to be the remains of the ossified sclerotic, since the sketch shows a form similar to that found in other Osteostraci in which the sclerotic is preserved The orbits are rather far forward on the shield, (or the pectoral sinuses far back), for the distance from the rostral angle to the level of the sinuses is about 2 4 times that from the rostral angle to the anterior margin of the orbits. The dorsal field is short and oval, extending just to the level of the endolymphatic apertures. It is bordered by a slight ridge. The lateral fields are relatively short, starting about the level of the nasal fossa and extending back to within 2 mm. of the pectoral sinus. A ridge capped with prominent tubercles is situated along the lateral border of the lateral field, extending not quite to its posterior end but slightly anterior to its forward end. I have not been able to discover any plates covering the fields, but in one specimen part of one field appears to be covered by a layer ornamented similarly to the general surface. The dorsal surface is ornamented with tubercles. Anteriorly there are prominent tubercles on the ridge of the nasal fossa and on the ridge lateral to the lateral field. Somewhat smaller tubercles are scattered generally over the surface, with still finer ones between the larger tubercles. Over the occipital region and that portion of the trunk which is covered by the shield there are three rows of prominent tubercles on either side, with usually four large tubercles in each row, and the median crista is surmounted by a row only slightly less prominent. Smaller tubercles are scattered, and to some extent arranged in longitudinal rows, between the main ridges, while fine tubercles are scattered among these and, in some cases,

arranged in rings about the bases of the large ones, reminding one of the ring of pedicellariae surrounding the base of a starfish spine. The posterior portion of the dorsal shield shows indications of fused segments. Usually only two of these are marked off, but the ridges of four prominent tubercles show an arrangement suggestive of the entire occipital region having been segmented. The margin of the shield has thin, fairly large, elongated tubercles. The same type is shown on the ventral rim which borders the oralo-branchial chamber laterally. The ventral ornamentation is known only on the cornua and on a few fragments of the ventral rim. On the cornua it is made up of fine, elongated tubercles. The margin of the oralo-branchial chamber is known only on a few fragments, but the traces of the apertures on these are very similar to those on better known cephalaspids.

The sensory canal system of *Thyestes verrucosus* was described briefly and figured in 1940(22). Portions of it on a number of counterparts of dorsal shields indicate a position unusually superficial. One such specimen Doctor Patten had etched lightly, bringing these canals into greater prominence. The system as revealed in these specimens shows great similarity to that of *Tremataspis*(23). The infraorbital starts lateral to the orbit, curves slightly forward and outward, following the distinct contour line about the base of the nasal eminence toward the midline. The lines from the two sides do not meet anteriorly. This canal consists of a continuous groove. The other traces of the system are dashed lines similar to those found on *Tremataspis*. Coursing posterolaterally from the posterior end of the infraorbital is a series of three dashes forming the post-orbital line. Postero-lateral to this and more decidedly off-set than in *Tremataspis* is the main lateral line, a series of dashes, four in number, extending to the posterior margin of the shield. A single dash about opposite the center of the dorsal field corresponds to the anterior transverse of *Tremataspis*, and a series of three dashes cuts transversely from near the endolymphatic aperture to the border of the lateral field on either side, forming the supraoccipital. Just anterior to the lateral field is an anterior marginal line.

Some trunk plates are known, showing a transverse row of fairly prominent tubercles with scattered smaller ones between, similar to the segmentation trace ornamentation on the posterior portion of the dorsal shield.

Witaaspis schrenckii (PANDER).

1856 *Cephalaspis schrenckii* Pander (3) p. 47, Pl. IV, fig. 2.
1858 *Cephalaspis schrenckii* Huxley (9) p. 269.
1858 *Cephalaspis schrenckii* Schmidt (10) p. 170, 184.
1866 *Trematapsis schrencki* Schmidt (12) (in part).
1891 *Trematapsis schrencki* Smith Woodward (13).
1892 *Tremtaspis schrencki* Rohon (4) p. 61, Pl. II, figs. 14, 15.
1892 *Cephalaspis schrencki* Schmidt (14) p. 99.
1894 *Thyestes schrencki* Schmidt (24) (in part) p. 206, Pl. I, figs. 3, 4, 5, 6, 9, ?7, ?8. (Not figs. 1 and 2.)
1895 *Thyestes schrencki* Rohon (16) figs. 1-5.
1927 *"Cephalaspis" schrencki* Stensiö (25) p 295 (not fig 2, Pl. 48).
1932 *"Cephalaspis" schrencki* Stensio (20).
1939 *Wittaaspis schrenckii* Robertson (5).

"Cephalaspis" schrenckii (Pander) has been redescribed in a new genus, *Witaaspis*. As pointed out in that paper and also in a note concerning *Tremataspis* (23), Schmidt really made this species the genotype of *Trematapsis* (12), and when he later removed it from that genus (14) he should have reduced the name *Trematapsis* to a synonym and should have given the genus represented by *Trematapsis schmidti* a new generic name. I have in the two references mentioned chosen to disregard the taxonomic conventions on the grounds that more confusion would result from rectifying that ancient error than from letting it stand.

Witaaspis schrenckii is a small cephalaspid, with a shield about 15-17 mm. long, about 20 mm. broad at the level of the pectoral sinuses. The dorsal shield is abruptly arched anteriorly. Anteriorly and laterally it has a raised marginal rim, about 1.25 mm. wide, going smoothly over the edge of the shield. The general surface is ornamented with fine granular tubercles and is divided into slightly arched, polygonal areas separated from one another by smooth, shallow grooves. Cornua and pectoral sinuses are rudimentary. The trunk division of the shield is moderately long. The orbits are large and nearly circular in outline. The naso-hypophysial fossa is deep, with the aperture on a prominent ridge in the fossa. The dorsal field is large, oval, and bordered by ridges. The lateral fields are long, extending nearly to the cornua. The crista is low. Of the sensory canal system the infraorbital, postorbital, supraoccipital, and a trace of the main lateral

line are known. These resemble the corresponding lines of *Tremataspis.*

Witaaspis patteni ROBERTSON (6).

In 1940 the writer described this new species of *Witaaspis* from specimens in the Patten collection. Like the other species it is a small form, about 17 mm. long by 20 mm. broad. Cornua and sinuses are rudimentary. It differs from *Witaaspis schrenckii* in ornamentation, the general surface being covered with fine granular tubercles but not divided into polygonal fields, and in having a prominent mid-dorsal crista on the shield.

Saaremaaspis mickwitzi (ROHON).

1892 *Tremataspis mickwitzi* Rohon (4) (in part).
1938 *Saaremaaspis mickwitzi* Robertson (23).
1938 *Saaremaaspis mickwitzi* Robertson (7).

Saaremaaspis mickwitzi has a shield about 18 mm. long and 19 mm. wide. The cornua are short and broad, the pectoral sinuses narrow and deep. The orbits are large and are about one-third of the way from the rostral margin to the level of the sinuses. The lateral fields are short, especially posteriorly. The dorsal field is nearly oval and large. The naso-hypophysial fossa lies between the anterior parts of the orbits. The anterior of the shield is bluntly rounded. Prominent ridges lie mesial to the posterior portions of the lateral fields and extend back to within about 1 mm. of the sinuses. The ornamentation consists of very fine granular tubercles.

Cephalaspis oeselensis ROBERTSON (8).

The shield of this species is approximately 23-29 mm. long, the width at the level of the pectoral sinuses about 30-37 mm., varying with the degree of flattening. The cornua are moderately long and broad, the distance from the rostral angle to the cornu tip being 3.6 to 4.4 times the cornu length, that length being about 1.5 to 2 5 times its width at the cornu base. The orbits are of medium size, oval in form. The naso-hypophysial fossa is wide and deep, the foramen long and in a prominent ridge in the fossa. The dorsal field is narrow, lenticular, and bordered by ridges. The endolymphatic apertures are within the field. The lateral fields are long, from forward of

the nasal level to the base of the cornua. Apparently six nerve trunks run to each lateral field, the two anterior trunks being within a common encasement until about half way between the orbit and the field The ornamentation consists of spine-like tubercles or denticles, each in the center of a polygonal area. The marginal tubercles are elongate, bun-shaped, somewhat like those found on the cornua, except that on the cornua they tend to mass together near the tip. The pectoral sinus margins are denticulate. The posterior border of the dorsal shield shows traces of segmentation.

The superficial portions of the shields are not well-preserved in most cases, and when they are preserved they are extremely difficult to uncover, since the tubercles are fine, spinous, and brittle. A number of specimens exhibit details of nerve and vessel distribution and there are portions of the braincase available.

It is of considerable interest to find in this early horizon a typical *Cephalaspis*, with well-developed cornua Heintz (26, p. 101) suggested a phylogenetic series of cephalaspids, starting with such forms as *Ateleaspis*, *Aceraspis*, and *Micraspis*, in which the cornua are either absent or rudimentary, and going through *Hemicyclaspis*, with rudimentary cornua, to typically cornuate forms. He went on to analyze this series in terms of certain other anatomical features. In each case where *Cephalaspis* appeared to fit into the series it was placed last, but the apparent order of development of the other forms was varied. He remarked (p. 105) "It is somewhat difficult to unite these lines [of specialization] and it is difficult to say which of them is the more correct. The most probable is, however, as in so many cases, that none expresses the true condition, and that the development of cephalaspids has proceeded on many independent, more or less parallel lines."

While the finding of a typical *Cephalaspis* in a horizon antedating those in which the "more primitive" forms have been found does not necessarily invalidate the theory, it at least makes one hesitate in accepting it in the absence of further evidence.

The genus *Cephalaspis* is of interest in one further respect. The Oesel material is regarded as of Lower to Middle Ludlow (26, p. 109), the oldest horizon from which Osteostraci have been described. It has also been described from the Downtonian, from Lower Devonian, Middle Devonian, and Upper Devo-

nian. Moreover it has been described from regions as far apart as Poland and Wyoming. This represents a wide geographical distribution and a long life for a genus, especially if one is to regard ostracoderms as a group of fresh-water forms (27). Of course the fact that *Cephalaspis* is the type genus of the family makes it probable that cephalaspids whose generic identification is uncertain would be more likely to be assigned to this than to other genera of the family. However, a great many of the species, ranging from Upper Silurian to Upper Devonian, have been described by Doctor Stensiö or by workers who have consulted with him, and his thorough knowledge of this genus makes the geological distribution appear valid.

Classification of the Osteostraci.

I am not sure that the present is the time for a thorough revision of the Osteostraci, but possibly a discussion of the basis for our taxonomic categories in the group will stimulate others to make like contributions and from these we may arrive at certain principles to govern us in delimiting our groups.

Regan(28) has stated that a species is any group which has been so listed by a competent taxonomist, and I think we can go little beyond that in our general definition at present. Here is one field in which a more extensive study of mutations, covering a wide variety of organisms, may eventually aid taxonomy, but we are far from that as yet.

Taxonomic categories, though we like to feel that the grouping they segregate have a real genetic significance, are largely conventional. Ideally they aim to express varying degrees of relationship among organisms, successive categories being increasingly inclusive as we go from species upward, but there is certainly nothing especially significant about the category "species" which places it apart from other categories. Since we find a binomial classification convenient, however, it seems to me advisable to make little use of categories lower than this except for such groups as birds, in which geographical races are so abundant. Especially do I feel the importance of this in the classification of fossil forms. So many of the features of living creatures are unavailable in fossils that we may well attach greater taxonomic significance to recognizable differences in fossils than we might in living forms. There may be exceptional cases in which more inconvenience would attach

to creating new species than to splitting a species into varieties, but I feel that the latter should in general be avoided.

The general rule which I have tried to follow is to treat as a species any fossil form which is distinctive enough to be recognizably different from other forms, trivial individual differences excepted. For example in studying *Tremataspis* I found that there was a large group of individuals showing a common form of nasal aperture and fossa, dorsal crista, etc., and a recognizable basic pattern in distribution of the dorsal tubercles, but wide variation in the number and detailed pattern of the tubercles. That group I regard as a single species, nor do I feel that anything would be gained by splitting it into a series of varieties on the basis of those variations in tubercle distribution. On the other hand I found one individual showing a nasal form similar to one species, a tubercle distribution similar to but not identical with a second, and a crista more like a third species. This individual I regard as representing a distinct species, and I believe that to call it a variety of any of the other three would place it in a false category.

As regards species I tend to be a "splitter," because I believe the function of the category "species" is to express slighter differences between groups of individuals, enabling us to specify more exactly the individuals to which we wish to refer in any way.

The category "genus" starts an ascending scale of inclusiveness. Here we have two functions, to specify as clearly as possible a particular group of species, and to express important similarities within this group. It is important to make our genera broad enough to include closely related species and yet restricted enough to enable us to arrange our species in groups.

Similar considerations apply to the still more inclusive categories of family, order, etc., and there is perhaps no more impressive argument for the major tenet of organic evolution than the knotty problems which face the taxonomist in attempting to strike a balance between these two functions of classification.

The Osteostraci seem to form a natural group. All of them possess bony shields which enclose the head and generally something of the trunk as well. The naso-hypophysial aperture is unpaired and situated dorsally. The orbits are high dorsally and approximated, with a pineal saddle between them.

They all have depressed areas posterior to the orbital region, which were probably covered by bony elements in all cases originally, although these elements are rarely preserved. Similar depressed, plate-covered areas lie near each lateral margin. These two sets of structures have had a variety of functions assigned to them. A number of workers following Stensio(25) refer to them as dorsal and lateral electric fields I refer to them simply as dorsal and lateral fields. The ventral side has a large oralo-branchial chamber in its anterior part, which was apparently covered by a membrane reenforced with an armor of bony plates. These are rarely preserved, although in a few specimens we have found sufficient preservation to reconstruct their pattern. Posterior to this chamber may be a solid portion of the shield or there may be only bony plates or scales covering the rest of the venter. Branchial apertures are ventral, along the margins of the oralo-branchial chamber.

The trunk region posterior to the shield, and the caudal region are known in detail in few specimens, but the traces we do find in others conform to the pattern found in those better known. This region has dorsally a row of capping scutes, laterally two or three longitudinal rows of dorso-ventrally elongated, narrow plates, somewhat like those of the *Anaspida*, and ventrally more irregularly arranged scales The form of the tail may be heterocercal or diphycercal. Hypocercal forms are found in Heterostraci but thus far have not been found in the Osteostraci.

In 1935(29) I listed four families in the Osteostraci: Cephalaspidae, Tremataspidae, Dartmuthiidae, and Oeselaspidae. Diagnostic characters of these families are as follows:

1. Cephalaspidae.

The shield covers the head and extends back a short distance onto the trunk. Cornua are present, but may be rudimentary. Lateral fields are undivided. Dorsal and ventral shields are fused marginally in some cases. The ventral shield posterior to the oralo-branchial chamber is generally short. Oralo-branchial plates are known in but a few forms, and in these they are relatively small and numerous. The caudal fin is rarely preserved, but in those specimens in which it has been observed it is heterocercal.

2. Tremataspidae.

The shield covers the head and trunk. Cornua are absent. Lateral fields are divided into an anterior and a posterior

field. Dorsal and ventral shields are fused marginally. Since the ventral shield is as long as the dorsal, the two are commonly found as a solid encasement. Oralo-branchial plates are few and relatively large, with a definite pattern in their arrangement. The caudal appears to be diphycercal.

3. Dartmuthiidae.

The shield covers the head and most of the trunk. Cornua are absent. The postero-lateral corners of the shield are slightly produced, but these corners are not homologous with the cornua found on cephalaspids. The lateral fields are undivided. Dorsal and ventral shields are fused marginally. The ventral shield posterior to the oralo-branchial chamber is covered by a mosaic of fine plates which sometimes remain attached and also show a loose connection to the ventral rim. Oralo-branchial plates are large and few.

4. Oeselaspidae.

The shield covers the head and most of the trunk. Cornua are rudimentary and pectoral sinuses face laterally. Lateral fields are divided as in Tremataspidae. Dorsal and ventral shields are fused marginally. Oralo-branchial plates are incompletely known but those observed are relatively large.

The Trematasрidae and Oeselaspidae are represented by but one genus each. Others have at times been assigned to Tremataspidae but have been shown later not to belong to that family. In my description of *Rotsikullaspis* (7) I did not assign it to any family, but it appears nearer to the Dartmuthiidae than to any of the others, and in 1939 (8) I assigned it to that family.

The Cephalaspidae includes a number of genera. In 1932 Stensiö (20) divided it into two sub-families, the Cephalaspinae and the Kiaeraspinae on the basis of the form of the lateral fields and the course of the anterior nerves to these fields.

The genera which he assigned to the Cephalaspinae are: *Cephalaspis* Agassiz, *Hemicyclaspis* Lankester, *Ateleaspis* (?) Traquair, *Micraspis* Kiaer, and *Aceraspis* Kiaer.

To the Kiaeraspinae he assigned: *Thyestes* Eichwald, (*Auchenaspis* Egerton), *Sclerodus* Agassiz, *Didymaspis* Lankester, *Benneviaspis* Stensio, *Securiaspis* Stensio, *Hoelaspis* Stensio, *Boreaspis* Stensio, and *Kiaeraspis* Stensio.

Stensio characterized the Cephalaspinae as follows (p. 76): "*Cephalaspidae* with electric fields well developed. Lateral electric fields devoid of distinct postero-median angle. Inde-

pendent canals of two most anterior nerves of lateral electric fields fairly long, their common canal ending just antero-laterally to the orbit. Canal of nervus trigeminus proper passing down to oralo-branchial chamber in space between independent canals of two most anterior nerves to lateral electric fields. Canal of dorso-lateral superficial vein 3 usually opening into postero-lateral corner of orbit."

Of the five genera assigned to this sub-family, three, *Ateleaspis*, *Micraspis*, and *Aceraspis*, were inadequately known at the time. *Ateleaspis* had been described by Traquair(30, 31). *Micraspis* and *Aceraspis* had been briefly characterized by Kiaer(32, 33). In 1939 Heintz(26) published a thorough account of all three forms. His descriptions form the basis for the brief accounts to follow.

Ateleaspis is about 19-20 cm. from the rostral angle of the shield to the end of the heterocercal tail. The shield is relatively short, about 4.5 cm., and apparently covered very little of the trunk. Cornua and pectoral sinuses are undeveloped. The posterior of the shield has lateral "lappet-like expansions," to use Traquair's term, which Heintz interprets as pectoral fins similar to those found on some other cephalaspids. The lateral fields are broad and long, the dorsal field short. The orbits are in front of the median part of the head shield. The naso-hypophysial aperture is between their anterior ends. There are two dorsal fins. Little is known of the ventral surface, but the oralo-branchial plates apparently were minute.

Aceraspis also lacks cornua and pectoral sinuses. What appears to have been a fin-like protrusion occurs at each postero-lateral margin of the shield. The body length in the one species known is about 17-18 cm., the shield length about 47-48 mm., its breadth about 50 mm. The shield in general is very similar to that of *Hemicyclaspis*. It covered the head and a short segment of the trunk. Posterior to the shield the body is encased in scales similar to those of other cepahalaspids. Two dorsal fins and a heterocercal caudal are indicated. The orbits, with the pineal plate between them and the naso-hypophysial fossa in part between their anterior ends, are somewhat less than half way between the rostral end of the shield and the level of attachment of the pectoral fins. The lateral fields are long and broad, the dorsal long and lenticular. The oralo-branchial fenestra was covered with small, angular scales.

The shield rim resembles that of *Dartmuthia*. The rim continues around the fenestra except that it is incomplete posteriorly, where the gap is filled in with scales like those covering the chamber.

Micraspis is a smaller creature. Lappet-like pectoral fins similar to those of *Aceraspis* are found, but again there are neither cornua nor pectoral sinuses. The lateral fields are long and broad, the dorsal field long and narrow. The plates over the oralo-branchial fenestra are varied in size and shape. The posterior and lateral ones are large, those of the central area smaller and very irregular, and a group of pre-oral plates small but more regular in pattern. The ventral shield is not closed behind the fenestra but is completed by scales. The fins are much like those of *Aceraspis*.

Hemicyclaspis has a short shield with rudimentary cornua and pectoral sinuses and with pectoral fins like those of *Micraspis*. The oralo-branchial plates are small, numerous, and irregular in arrangement. The venter posterior to the chamber is closed with irregular, scale-like plates. Lateral fields are long, ending just anterior to the sinuses. The dorsal field is long to medium. The orbits are about half way back from the rostral margin to the sinus level. An anterior dorsal fin is represented by a long dorsal crest consisting of a series of scutes. A posterior dorsal fin is located far back.

Cephalaspis has a relatively short shield. The cornua are quite variable but generally are at least as long as the trunk division of the shield. Pectoral sinuses are well-defined. The ventral shield posterior to the oralo-branchial chamber is short, and in most species is not preserved. How closely fused it was with the dorsal shield is thus in most cases not known. In some at least the fusion marginally seems to have been complete. The oralo-branchial plates are known in very few specimens. In these they seem to have been roughly as in *Hemicyclaspis*, small, numerous, and irregular in arrangement. The lateral fields are long, extending at least to the cornua in those species in which the fields are available. The dorsal field is relatively long, starting immediately behind the pineal plate and extending behind the region of the endolymphatic apertures, which, in many cases at least, seem to have opened within the field. Generally the orbits are located about half way between the rostral margin and the level of the pectoral sinuses. In one species, *Cephalaspis staxrudi* Stensiö, the

orbits are very far back, about 0·7 of this distance. The naso-hypophysial fossa and aperture lie in part between the forward portions of the orbits. Pectoral appendages are known in some cases. They protrude from the pectoral sinuses, are scale-covered, and sometimes are margined with heavy scales.

The sub-family Kiaeraspinae was characterized by Stensiö as follows: "Electric fields well developed in certain forms, fairly short in others. Lateral electric fields usually with postero-median angle, strongly developed in some forms. Independent canals of two most anterior nerves to lateral electric fields short or absent, their common canal extending close to, or even into, lateral electric fields. Canal of nervus trigeminus proper passing down to oralo-branchial chamber either entirely posteriorly, or entirely anteriorly, to canals of two most anterior nerves of lateral electric fields. Canal of dorso-lateral superficial vein 3 usually opening into canal of post-orbital division of vena capitis lateralis."

Thyestes (=*Auchenaspis*) has been described earlier in this paper, but may be briefly characterized again. The shield is relatively long, the posterior portion showing traces of segmentation, or as though it might have formed by fusion of some anterior scutes of the post-shield region. Cornua are of medium length, up to the length of the interzonal part of the shield. (They are shorter in *T. salteri* and *T. verrucosus* than in *T. egertoni.*) Pectoral sinuses are fairly well developed. The ventral shield is fused marginally with the dorsal. Lateral fields are short both anteriorly and posteriorly. A slight postero-median angle is present on these fields. The dorsal field is short, extending only to the endolymphatic apertures Oralo-branchial plates are known only on a fragment, and appear to have been small and numerous. The orbits are slightly less than half way from the rostral margin to the level of the pectoral sinuses. As mentioned earlier in this paper, the sensory canal system resembles that of *Tremataspis* more than that of any other cephalaspid in which the system is known.

Sclerodus (=*Eukeraspis*) has a fairly short shield, incompletely known posteriorly. The shield margin is fenestrated in the one species known. The cornua are very long, longer than the shield. The pectoral sinuses appear to have been shallow and ill-defined. The ventral aspect is unknown. Lat-

eral fields are short, anteriorly and posteriorly. The dorsal field is incompletely known. It is separated from the pineal by an elevation. The orbits are about three fifths of the way back from the rostral margin to the sinus level.

Didymaspis has a long shield, encasing nearly or quite the entire trunk, resembling *Tremataspis* and *Oeselaspis* in this respect. Dorsal and ventral shields are fused marginally. Cornua and pectoral sinuses are rudimentary, located about half way back along the lateral margin of the shield, and the sinuses face laterally. Oralo-branchial plates are unknown. The lateral fields are short anteriorly, somewhat like those of *Sclerodus*. They have a postero-median angle which amounts to an extension of the field about three fifths as long as the main field, extending past the sinuses. The dorsal field is short, extending just to the endolymphatic apertures. The orbits are slightly over half way from the rostral margin to the sinus level.

Benneviaspis has a shield broad and short, with very much produced postero-lateral angles. Cornua are fairly well developed, not extending beyond the interzonal part of the shield. Pectoral sinuses are broad and shallow. Dorsal and ventral shields are fused marginally. The ventral shield posterior to the oralo-branchial chamber is short. Lateral fields are long, extending nearly to the tip of the cornua, and have a pronounced postero-median angle The dorsal field is fairly long. The orbits are more than half way back from the rostral margin to the sinus level.

Securiaspis has a broad, depressed shield of medium length. The cornua extend back at least as far as the interzonal part of the shield. Pectoral sinuses are broad and deep. Lateral fields are long, extending just onto the cornua, and the dorsal field is long. The venter is unknown The orbits are about three fifths of the way back on the shield.

Hoelaspis has a broad shield of moderate length, with a definite rostral process. Cornua are long and stout, and directed laterally. Consequently the sinuses are shallow and very ill-defined. Lateral fields are long, extending onto the cornua and have a distinct postero-median angle. The dorsal field is long. Orbits are about two thirds of the way back from the tip of the rostrum to the sinus level, about one third of the distance from the base of the rostrum.

Boreaspis has a shield of medium length, with a very long,

slender rostral process. The cornua are slender and shorter than the interzonal part of the shield. Pectoral sinuses are distinct. The lateral fields are long, but not extending onto the cornua, and have a postero-median angle or extension directed backward parallel to the lateral margin of the interzonal part of the shield, somewhat like the extension of the fields found in *Didymaspis*. The dorsal field is of medium length. The posterior region of the ventral shield is fused marginally with the dorsal shield. The orbits are about two thirds of the way back from the rostral margin to the pectoral sinuses, not including the rostrum.

Kiaeraspis has a long shield, the posterior part with traces of segmentation. Dorsal and ventral shields are fused marginally. The ventral shield posterior to the oralo-branchial chamber is unusually long. Cornua are short and broad, sinuses slight. The lateral fields extend back to the pectoral sinus level. They have a curve posteriorly which points their ends about parallel to the interzonal part margin. The dorsal field is long and narrow. A pronounced median crista is present. Orbits are about half way back on the shield.

The genera *Witaaspis* and *Saaremaaspis* have been described earlier in the paper, but may again be briefly characterized.

Witaaspis has a shield of moderate length, with rudimentary cornua. The lateral fields are of medium length, reaching almost to the cornua. The dorsal field is also of moderate length.

Saaremaaspis is characterized by very short lateral fields, short but distinct cornua, and broad oralo-branchial chamber. The eyes are about one third of the way back from rostral margin to sinus level.

In 1939 Heintz(26) described some cephalaspids from the Downtonian of Norway and included a discussion of the classification of the cephalaspids. In his classification he raised the cephalaspid group to sub-ordinal rank and the two sub-families of Stensio to that of families. He then erected a third sub-family, the Hemicyclaspinae. His outline classification is incomplete. One would like to have had him include all the families and genera of Osteostraci. As it stands it is as follows:

Order Osteostraci
  Sub-order Cephalaspida
    Family Cephalaspidae

Sub-family Hemicyclaspinae
Genera: *Ateleaspis, Aceraspis, Micraspis, Hemicyclaspis*
Sub-family Cephalaspinae
Genus *Cephalaspis*
Family Kiaeraspidae
Sub-order Tremataspida

This opens the question of the disposition of the genera listed by Stensio under the Kiaeraspinae. Stensiö had hinted (20) that possibly this group could be further broken up, and Heintz suggests that possibly such a change will result from the work which Wangsjo had then in progress on the cephalaspids from Spitsbergen.

Heintz does not attempt to place the families Dartmuthiidae and Oeselaspidae in this scheme, but if it were to be adopted their disposition would need to be settled, either by placing them under one of the two new sub-orders or by raising them to sub-ordinal rank. If the latter alternative is taken it erects four sub-orders in the order, one with two families, at least two sub-families, and fifteen genera; one with two genera, each represented by a single species; and two with a single genus. I hesitate over taking the step of erecting a sub-order to include but one genus, although that is not impossible.

Heintz remarks (p. 95) in commenting on his classification: "The paper of Robertson has also shown that between *Tremataspidae* is a number of quite independent groups." Presumably he referred to my paper on the Tremataspidae(23) which included an outline classification of the Agnatha down to families.

The problem which Heintz faces here is familiar to taxonomists. He has found reason to separate off a group of genera from others listed as belonging to the same sub-family. This can be done in one of two ways, one by raising the old sub-families to family rank, and the old families to sub-ordinal rank or to that of super-families; the other by introducing additional categories, such as super-genera. This also raises some objections.

It has seemed to me that one might find some basis for a solution to this problem by analysis of the familial and generic characters which have been used by workers in the taxonomy of this group. One might find that some of the generic distinctions were sufficient to be given familial significance.

In tabular form the four families may be characterized as follows:

Cephalaspidae	Tremataspidae	Dartmuthiidae	Oeselaspidae
Cornuate	Acornuate	Acornuate	Cornua rudimentary
Shield covers head and small part of trunk	Shield covers head and trunk	Shield covers head and most of trunk	Shield covers head and trunk
Lateral fields single	Lateral fields broken	Lateral fields single	Lateral fields broken
Oralo - branchial plates small	Oralo - branchial plates large	Oralo - branchial plates large	Oralo - branchial plates large
Dorsal field reaches endolymphatic apertures	Dorsal field not to endolymphatic apertures	Dorsal field not to endolymphatic apertures	Dorsal field not to endolymphatic apertures
Caudal heterocercal	Caudal diphycercal		

Before proceeding to a discussion of sub-families and genera it may be of some value to consider the anatomical significance of these diagnostic characters.

1. The presence or absence of cornua and pectoral sinuses was probably correlated with the presence, absence, or form of the pectoral appendages. The presence or absence of these appendages would involve other differences, such as, perhaps, the form of the caudal fin. This was discussed in the analysis of the Tremataspidae(23).

The form of the cornua, depth of the sinuses, etc., may or may not have significance. With rudimentary cornua and sinuses in *Hemicyclaspis* and their apparent absence in *Ateleaspis*, *Aceraspis*, and *Micraspis* we find well-developed pectorals. What the significance of the small, laterally directed sinuses of *Didymaspis* and *Oeselaspis* may have been I do not know. It is difficult to visualize pectorals there. In both cases the condition is correlated with a long trunk portion of the shield, almost like *Tremataspis*.

2. The enclosing by the shield of a greater or lesser portion of the trunk in a non-segmented encasement would seem to call for differences in locomotion, with probable alteration of unpaired fins.

3. The function of the oralo-branchial plates over the venter of the oralo-branchial chamber was probably flexibility of the throat as an aid either in suction or in respiration or in both. As Stensio has pointed out(25), these plates were undoubtedly embedded in a membranous covering of the chamber. There are various rugosities on the plates and on the inner aspect of the shield but thus far not enough is known about these to warrant an attempt to reconstruct muscular mechanisms. The significance of small and numerous or large and few plates is not apparent. Some suggestions have been made that certain of the plates may have served as food-manipulating "jaws," but such speculations need much more working over before they warrant acceptance.

4. The form of the lateral and dorsal fields may have had a bearing on their mode or degree of functioning, but what their function was we do not know. The form of the lateral fields was correlated with differences in nerve distribution.

As pointed out previously, Stensio(25) divided the Cephalaspidae into two sub-families, Cephalaspinae and Kiaeraspinae, and Heintz(26) separated off four genera from the Cephalaspinae as a sub-family, the Hemicyclaspinae, and erected a sub-order Cephalaspida, with two families, Cephalaspidae and Kiaeraspidae

The characters used by Stensiö included some not available in most specimens, such as the nerve distribution to the lateral fields. Using a series of characters in approximately the same anatomical category as those used for the families, one can tabulate the characters of the Cephalaspinae (as redefined by Heintz), Hemicyclaspinae, and Kiaeraspinae as follows:

Cephalaspinae	Hemicyclaspinae	Kiaeraspinae
Cornua at least as long as the interzonal shield	Cornua rudimentary or absent	Cornua usually well developed (rudimentary in *Didymaspis*).
Pectoral sinuses definite.	Pectoral sinuses indefinite, rudimentary or absent.	Pectoral sinuses broad (rudimentary in *Didymaspis*)
Lateral fields long.	Lateral fields long.	Lateral fields usually long (*Thyestes, Sclerodus, Didymaspis, Saaremaaspis* exceptions)
Dorsal field long	Dorsal field long or medium	Dorsal field long (except *Didymaspis* and *Thyestes*).

These distinctions seems to me to be insufficient to justify separation as families, but I am in agreement with Stensiö and Heintz as to their validity as sub-families. Whether the difference in nerve distribution between Kiaeraspinae on the one hand and Cephalaspinae and Hemicyclaspinae on the other should be recognized taxonomically is an open question.

Generic distinctions in the cephalaspids are: posterior extension of shield, proportions of cornua and sinuses, length and form of lateral and dorsal fields, and relation of venter to dorsal shield.

Stensiö(25) lists as specific differences in cephalaspids: general shape and proportions of shield, configuration of the rostral margin, shape and direction and denticulation of cornua, shape and size of pectoral sinuses, shape and backward extension of interzonal part of shield, size and shape of orbital openings, shape and extension of lateral and dorsal fields, and ornamentation.

Comparison of the two lists would seem to indicate that no fundamental difference is recognized between generic and specific characters, the former in the main being quantitatively greater than the latter. As to the significance of our generic and specific characters there is little to be said. Any alteration in shield proportions or in the degree of flexibility of such shield parts as the post-branchial venter would probably entail other differences, some of which might be functional, but on the whole the characters listed seem to be physiologically trivial. This is to be expected of characters diagnostic of the lower taxonomic levels.

This study does not profess to be revisionary, and I have no intention to go into the validity of the cephalaspid species, numbering at least eighty. I find no grounds for rejecting any of the genera listed in this paper. The one problem which I do wish to consider is that of family rank.

Rohon(4) gave the Thyestidae family rank, but other writers have in general disagreed. As shown earlier in this paper, the sensory canal system exhibits a close similarity to that of *Tremataspis* and differences from that found on any other cephalaspid to date. However this system is so little known in cephalaspids that one can hardly use it as a basis for more than specific distinction The endolymphatic apertures lie

outside the dorsal field as they do in *Tremataspis*, *Oeselaspis*, and *Dartmuthia*. In most respects, however, the characters shown fall within the range of those typical of Cephalaspidae, and I would not place it as a distinct family or sub-family

Didymaspis has sometimes been placed with Tremataspidae, but Stensiö (20) has shown that it has single rather than divided lateral fields and that it has rudimentary pectoral sinuses, removing it from that family. He placed it with the Kiaeraspinae. The chief ground for separating it from the Cephalaspidae appears to be the great posterior extension of the shield, which, as Stensio (p 53) says, "*is so long that it undoubtedly* comprises almost the entire abdominal region." The question would be whether this character should be given greater weight than the presence of pectoral sinuses and undivided lateral fields In the extent of the shield over the trunk *Didymaspis*, *Tremataspis*, *Oeselaspis*, *Rotsikullaspis*, and *Dartmuthia* are very similar. *Didymaspis* and *Oeselaspis* have the same type of rudimentary pectoral sinuses In fact these two genera are sufficiently similar for Patten (34) to list *Oeselaspis* as *Didymaspis pustulata* The chief distinguishing features between these two genera are the divided lateral fields in the one, undivided fields in the other. The sensory canal system is different from that of any other known cephalaspid.

The undivided lateral fields seem to be the main reason for the inclusion of this genus under the Cephalaspidae, and even these are unique in the peculiar postero-median process of the field, extending well back on the interzonal part of the shield, behind the sinus level.

I would therefore favor separation of *Didymaspis* from the Cephalaspidae as an independent family, the Didymaspidae, characterized as follows: Shield covering the head and most of the trunk; pectoral sinuses rudimentary; lateral fields undivided but with long postero-median extension behind the pectoral sinus level. dorsal and ventral shields fused marginally.

As it stands at present my classification of the Osteostraci, down to genera, is as follows:

Order Osteostraci Lankester
  Family Cephalaspidae Agassiz
    Sub-family Cephalaspinae Stensio
      Genus *Cephalaspis* Agassiz

Sub-family Hemicyclaspinae Heintz
Genera *Hemicyclaspis* Lankester
Ateleaspis Traquair
Micraspis Kiaer
Aceraspis Kiaer
Sub-family Kiaeraspinae Stensio
Genera: *Kiaeraspis* Stensio
Securiaspis Stensio
Benneviaspis Stensio
Hoelaspis Stensio
Thyestes Eichwald
Boreaspis Stensio
Sclerodus Stensio
Witaaspis Robertson
Saaremaaspis Robertson
Family Tremataspidae Woodward
Genus *Tremataspis* Schmidt
Family Dartmuthiidae Patten
Genera *Dartmuthia* Patten
Rotsikullaspis Robertson
Family Oeselaspidae Robertson
Genus *Oeselaspis* Robertson
Family Didymaspidae N fam.
Genus *Didymaspis* Lankester

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ON FILM FORMATION OF WATER FLOWING THROUGH THIN CRACKS.

ROLAND MEYEROTT AND HENRY MARGENAU.

ABSTRACT The decrease with time in the flow of water reported by Wentworth has been investigated and found to depend not upon time but upon the amount of flow This, together with other evidence here presented, leads us to propose that the retardation of flow is due to the formation of small air bubbles on fractures or minute irregularities in the surfaces bounding the flow.

IN a recent investigation on the viscous flow of liquids, Wentworth[1] has described experiments in which he observed a decrease with time in the flow of water and other liquids through thin cracks. He attributes this retardation to formation of a film on the walls of the channels and suggests its consideration in the study of intermolecular forces. While this problem is of practical importance in the study of flow of ground water, its chief interest to the physicist lies in this implied promise that the phenomenon might lead to a determination of intermolecular forces or structure in liquids. Hence it seemed desirable to carry Wentworth's work further, either to substantiate his hypothesis of film formation or to find some new explanation of the retardation. Our results have led us to propose a different mechanism for the effect. We suggest, on the basis of evidence to be described here, that it is due to the formation of small air bubbles on fractures or minute irregularities in the surfaces and that these obstacles impede the flow.

The experiments were carried out with the use of the simple apparatus shown in Fig. 1. The water container is a commercial pyrex pie plate with a piece of plate glass 15 cm. in diameter cemented to the bottom. A hole .8 cm. in diameter was ground through the center and a glass tube fitted to serve as an outlet. A second piece of plate glass was mounted above the first by means of supports resting on the edge of the plate. The adjustment was accomplished by a micrometer screw of pitch 1/6 mm. The space between these two pieces of plate glass served as the adjustable "crack." All parts in contact with the water were glass.

[1] Wentworth, C. K : 1914, Amer Jour Sci., 242, 478

Before each run the equipment was thoroughly cleaned with concentrated NaOH solution, then with cleaning solution, and finally by rinsing in distilled water. Interference fringes were used to adjust the zero of the micrometers. The entire plate was kept under a bell jar to prevent contamination. No attempt was made to keep the temperature constant, so that

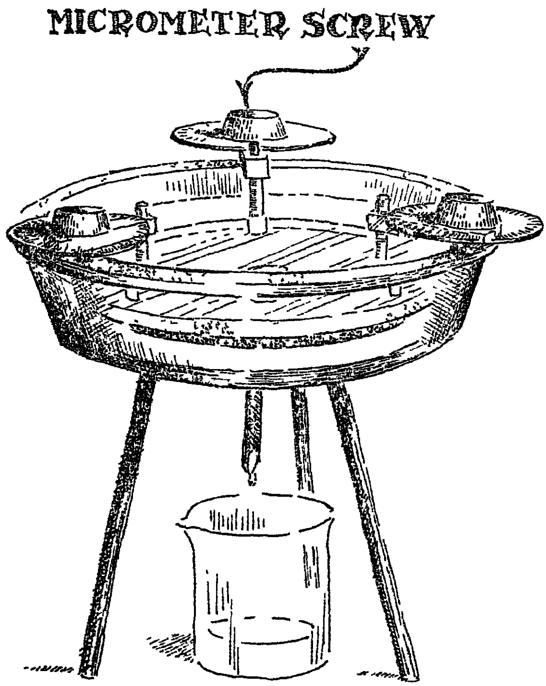

FIG. 1.

daily fluctuations in temperature had to be recorded. The rate of flow was measured by timing drops falling from the outlet (approximately .1 cc. per drop). The pressure head for most of these experiments was around 5 cm. of water.

RESULTS.

Little trouble was encountered in confirming Wentworth's experimental results. Table I shows typical data selected from a run continuing over twelve days. The water was allowed to flow continuously and the readings selected for the table

were those at T=21.00°C. The flow decreased by nearly 500 per cent. This is a slightly smaller rate of decline than that noted by Wentworth for flow between lapped basalt, but he does remark that the slowing down is less pronounced for glass surfaces.

TABLE I.

Dependence of Flow on Time.

Time (Minutes)	Rate (drops/sec)
0	0101
1,450	00870
2,669	00774
8,190	00479
16,920	00205

In addition to the time effect observed by Wentworth, we also measured a temperature effect much larger than can possibly be due to the change in dimensions. Attention was given to this aspect of the problem because it might allow discrimination between the various possible mechanisms responsible for the slowing of the flow. An adsorbed film, for example, would progressively disappear from the walls as the temperature increases and thus promote the flow. The opposite, however, is observed.

Table II shows several measurements taken at about the same time. The rate of flow is a *decreasing* function of the temperature with a coefficient of about $\frac{.00833-00682}{.65(00833)}=.28/°C$ The apparent viscosity thus *increases* with temperature beyond all reasonable measure; actually the normal viscosity decreases with temperature and with a coefficient of only .014/°C.

TABLE II.

Dependence of Flow on Temperature.

Time (Minutes)	Temperature (°C)	Rate (drops/sec)
1450	21 10	00833
1560	21 20	.00793
1600	21 55	00728
1650	21 75	00682

A check was made for any evidence of liquid structure by determining the variation of rate as a function of plate sep-

aration *d*. On the assumption of laminar flow, it may be shown that the rate *R* is given by

$$R = \frac{\pi}{6}\,\frac{(P_1 - P_2)d^3}{\mu \log \frac{r_2}{r_1}}$$

where $P_1 - P_2$ is the pressure difference, r_2 the outside radius of the plate, r_1 the radius of the outlet tube, and μ the viscosity. This variation of R with d^3 was indeed observed, but the data will not be submitted here, since more accurate measurements of this sort at even smaller plate separations have already been published by S. H. Bastow and F. P. Bowden.[2]

Finding no evidence for structure in the film, we proceeded to see whether the time effect is accumulative with the amount of flow. This was done by allowing the water to flow just long enough to measure the rate The results are shown in Table III It may be noted here that the rate was constant (disregarding the temperature effect) unless flow took place. This indicates that the change in R is *not a time effect* but *accumulative with flow.* Since we were using distilled water, the only source of contamination was air. Hence the plate was examined with a low power microscope, and small air bubbles were seen adhering to the fractures and scratches in the plate glass. The number and size of these increase with time.

TABLE III.

Time (Min.)	Temperature	Rate (drops/sec.)	Flow since last observations
0	18.45°	0243	Start
100	18 90°	.0230	No Flow
260	19 15°	0223	No Flow
400	19 40°	.0224	No Flow
1,405	18 80°	0206	Restrict flow during night
1,600	19 50°	0199	No Flow
2,695	19 55°	0192	No Flow
3,115	20 05°	.0185	No Flow
4,185	20 15°	.0184	No Flow
4,485	20 20°	0158	Flow
5,595	20 40°	.0118	Flow
7,110	19 75°	.0137	No Flow
8,310	19 20°	.0117	Flow
8,610	20 00°	.00927	Flow
9,810	19 10°	.00917	Flow

[2] Bastow, S H. and Bowden, F P 1935, Proc. Roy. Soc 151, 220

DISCUSSION.

The precipitation of air from the water would explain all the facts observed here and by Wentworth. The time effect is one of obstruction of the opening by adhering bubbles, while the unusually large temperature effect is due to the expansion of these obstructing bubbles. Wentworth observed an increase in rate with the jarring of his apparatus; we observe a decrease in rate upon jarring. This difference is due to the direction of the flow; in Wentworth's case it was out toward increasing r. Thus, any dislodged bubbles would in his case be carried into positions where the obstruction would affect the flow less, while in our case the reverse was true.

The bubbles seem to precipitate out only on scratches. This would probably explain why Wentworth finds a greater rate of retardation with lapped basalt than is found with glass. It is not likely that basalt will take on a surface as smooth as plate glass.

An attempt to eliminate air from the water proved unsuccessful with the present equipment. Water previously boiled but allowed to stand quickly becomes aerated, and we find the somewhat anomalous situation of air being absorbed in the water at the open surface and precipitating out at the cracks. (That the air bubbles probably come from the water and not from the solid surfaces is shown by the fact that retardation is accumulative with flow and does not occur in the condition of stagnancy.) Why such a preference is shown we do not know, but it seems understandable that sudden changes in the flow pattern, which occur near irregularities of the surfaces such as scratches and cracks, favor the formation of bubbles from air absorbed in the water. No doubt the solubility of air will also be affected by the small separation of the plates.

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PARASITIC WORMS IN PERMIAN BRACHIOPOD AND PELECYPOD SHELLS IN WESTERN AUSTRALIA.

CURT TEICHERT.

ABSTRACT. Borings apparently attributable to parasitic worms are not uncommon in Permian brachiopod and pelecypod shells in Western Australia. The nomenclature of *Clionolithes* and *Palaeosabella* is discussed and it is concluded that both names refer to boring sponges. Most of the boring worms of the Palaeozoic seem to be without available names. The new genus *Conchotrema* is established for certain types of worm borings in shells of Devonian, Mississippian and Permian age. Another genus is discussed, but not named.

INTRODUCTION.

RECORDS of parasitic shell-boring animals in the Palaeozoic are comparatively rare. The traces left by such organisms are mostly attributed to sponges and worms and numerous "generic" and "specific" names have been established for such remains. Boring sponges have been described from the Ordovician of Bohemia, and from the Devonian of New York and Germany as *Clionolithes*, *Topsentia*, *Clionoides*, *Olkenbachia*, and *Filuroda*; boring worms are known from the Devonian and Mississippian of U. S. A. and from the Devonian of Brazil and of Germany where they have been described as *Clionolithes*, *Caulostrepsis*, and *Palaeosabella*. Certain other types of borings are known to have been caused by parasitic Bryozoa (*Rhopalonariidae*, *Vinellidae* and others). However, it is not intended to review the subject here, and the reader is referred to discussions and summaries published by Clarke (1921), Moodie (1923), Abel (1935) and Solle (1938). If such borings are in the form of more or less straight or simply curved, single or branching, tubes they are usually ascribed to the activity of worms; if they are more irregular excavations, often branching out in dendritic fashion from some central hole, boring sponges are thought to have been responsible for them.

As far as I am aware no remains of shell-boring parasitic animals have ever been described from Australian rocks or from rocks of Permian age anywhere in the world, and it may therefore be of interest to announce their occurrence in Western Australia, where they are not uncommon in deposits of Permian age.

The borings made by these parasites are very similar to certain borings described from North America and elsewhere for which worms are now generally believed to have been responsible. Shells which have been infested by these parasitic worms have

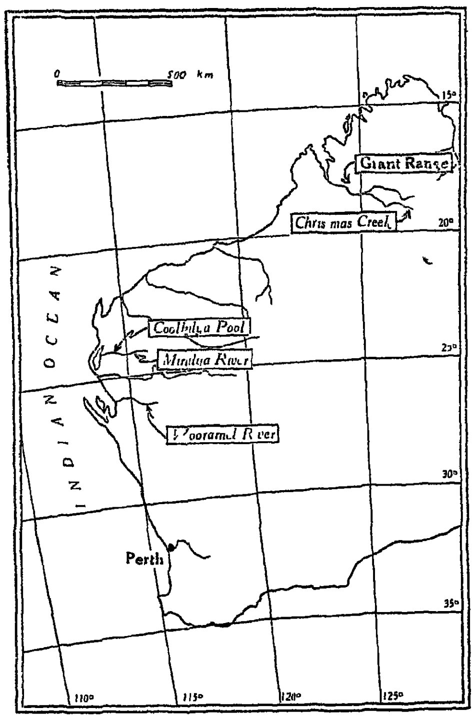


Fig. 1 Index Map of Western Australia, showing localities mentioned in the text

been found in such widely separated areas as on the Wooramel River at about 26° S. lat., on the Minilya River at about 24° S. lat. and in the Kimberley Division at about 18° S lat. It was found that these organisms as a rule attacked large shells rather than small ones, and although a more thorough search of the collections might bring to light additional specimens, it seems that large productids, spiriferids, and specimens of *Deltopecten* have been the most common objects of attack.

It is important to note that with one significant exception, in most of the brachiopod specimens observed the parasites restricted their attacks either to the dorsal valve, or if the

ventral valve was affected at all, the borings are mostly confined to the anterior edges and to the cardinal extremities. This observation seems to afford evidence for the conclusion that the parasitic organisms attacked living and not dead shells, and that, therefore, we are concerned with a case of true parasitism. Further notes on the ecology of the parasites will be found below.

TAXONOMY.

Unfortunately, the nomenclature of some of the remains of supposed boring sponges and worms is in a state of confusion and some historical remarks are necessary, before the Western Australian finds can be described and properly named.

The first attempt to describe, on a broader basis, parasitism and related phenomena among fossils was made by J M. Clarke in 1908 Among the new genera introduced by Clarke in that paper was *Clionolithes*, established to designate a certain type of borings in shells which he then thought were due to the action of boring sponges. Clarke included in this genus *Vioa prisca* McCoy (1855) and the new species *Clionolithes radicans*, *C. reptans* and *C. palmatus*. The three latter species came from the Devonian of North America, the first-named species had originally been described from the Silurian of England, but Clarke referred to it also a number of borings from the Devonian of North America. It is quite clear from Clarke's original text that he did not select a genotype when he established the genus, but that he chose the name for all the four species mentioned above without giving preference to any one of them.

In another paper, in 1921, Clarke recognised that *Clionolithes* in the sense in which the name had been used by him in 1908 comprised borings of two different types. He now thought that only the borings of *Clionolithes radicans*, *C. reptans* and *C. palmatus* had been made by sponges and that *Vioa prisca* and the specimens from North America which he had identified with this species were borings made by parasitic worms. Referring to his earlier paper he said that in 1908 he had "instituted the generic designation *Clionolithes* for a group which was based on the form described by McCoy from the Silurian as *Vioa prisca* and which was made by us to include not only tubes of that type, that is, straight subclavate fillings, but also very much smaller, much more intricate, arborescent or vagrant tubes." He thought that only the latter group was related to the sponges and that the name *Clionolithes* should

be restricted to it, "even though this may not be in precise accord with proper nomenclatorial procedure."

In this connexion it will be noted that in 1908 Clarke did not base *Clionolithes* on any one species, but on four species at the same time. If his intention was different, this does not appear from his text. Clarke was therefore in his formal right in 1921 to restrict the name *Clionolithes* to any combination of the original four species and this he did, again without selecting a genotype.

At the same time Clarke removed *Vioa prisca* to a newly established genus, *Palaeosabella*.[1] On pp. 90-91 he mentions the existence in the Devonian of New York of tubes which he believes to be due to the action of parasitic worms and continues as follows: "In seeking a designation for these tubes and burrows, we have noted the fact that they were described by McCoy under the name *Vioa prisca* from a Silurian mollusk. *Vioa* being an existing genus of boring sponges, and as we are convinced that such tubes as were indicated by McCoy are referable to the worms, a more appropriate name is required and we propose to apply to all of them the designation *Paleosabella* (sic) *prisca* (McCoy) disregarding differences in size, which are often obvious, and of the curvature, which are slight." Since no other species is mentioned in this paper in connexion with the generic name *Palaeosabella* the latter must be regarded as a monotypic genus which has *Vioa prisca* as its genotype, notwithstanding the fact that Clarke included in this genus many North American occurrences and that his conception of the genus was founded more on his American material than on the original *Vioa prisca* from England.

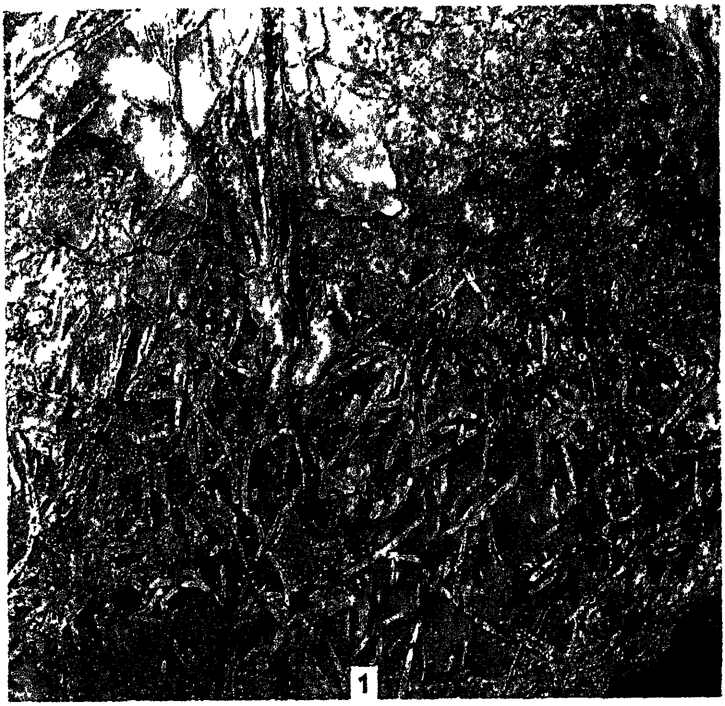
In the same publication (p. 88) Clarke established another

[1] When he introduced this name in the text (p 91, see quotation below) Clarke used the spelling "*Paleosabella*" In the explanation of all the text-figures, however, the adopted spelling is *Palaeosabella* which is therefore here accepted Solle, in 1938, spelt the name *Palaosabella*.

PLATE 1.

Fig. 1 *Conchotrema tubulosa* Teichert, n. sp, infesting dorsal valve of a productid. Nooncanbah series, 2 miles east of Christmas Creek Homestead, Kimberley Division, Western Australia Holotype no. 21319 X3

Fig. 2. *Conchotrema tubulosa* Teichert, n sp, infesting ventral valve of *Taeniothaerus subquadratus* Morris (?). Wandagee series, Minilv River, west of Coolkilya Pool, Northwest Division, Western Australia). 21441. X2.



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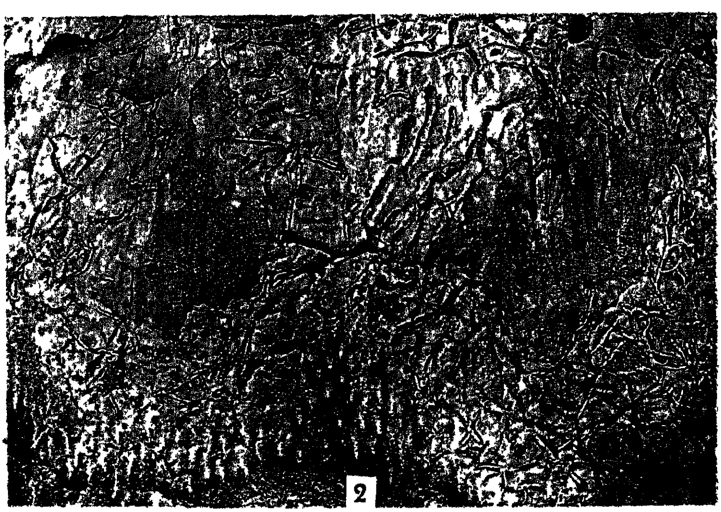

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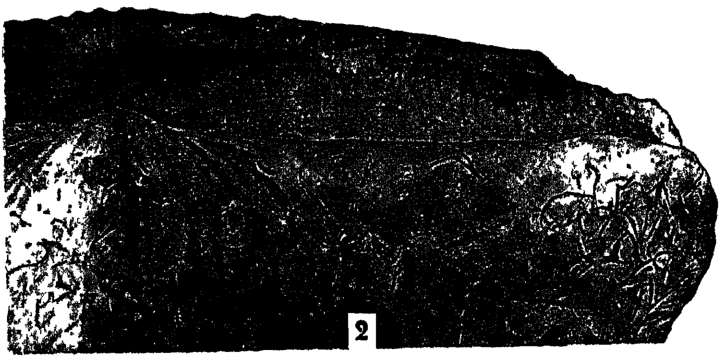

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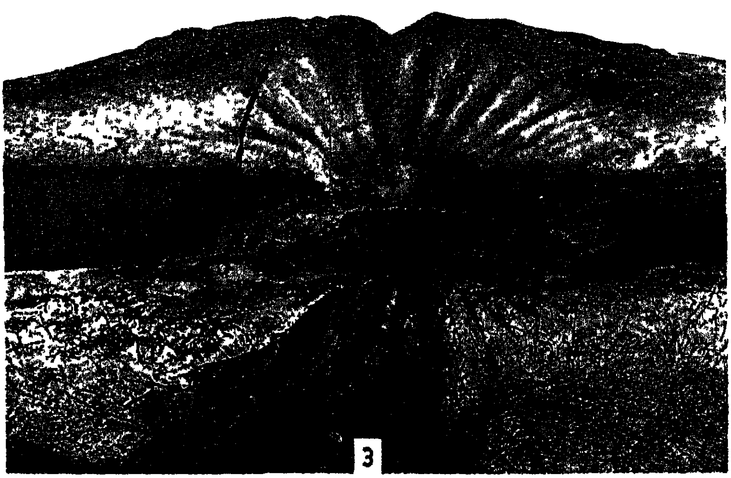

3

genus, *Topsentia*, with *T. devonica* as the only species which he referred to the sponges.

A genotype of *Clionolithes* was finally selected by Fenton and Fenton in 1932 (p. 43) who chose *C. radicans* Clarke. In addition to the species which Clarke had left in the genus these authors referred to it three additional species, viz. *Cliona hackberrensis* Thomas, and the new species *Clionolithes irregularis* and *C. fossiger*, all from the Devonian of North America. The authors share Clarke's revised opinion as to the nature of these remains.

Discussing *Vioa prisca* McCoy in another section of their paper Fenton and Fenton arrive at the conclusion that that species must probably be regarded as congeneric with *Topsentia devonica*. They describe it as "*Topsentia? prisca*" and refigure one of McCoy's original illustrations of the species. Furthermore, in their discussion of *Palaeosabella* on p. 51 they arrive at the conclusion that when proposing this name "Clarke considered only his American material, and both by implication and statement of characters excluded *Vioa prisca* McCoy. . . .; that *Palaeosabella* is based upon *P. prisca* Clarke, not on *Vioa prisca* McCoy; that the genus is without a genotype, implied or described; that if used at all . . . it should be based upon borings comparable to those shown in Clarke's Fig. 77, page 92, of *Organic Dependence and Disease*."

However, it seems to me that this proposed procedure is incompatible with the letter and spirit of the International Rules of Nomenclature. From the quotation I have given above from Clarke 1921 it must be evident that *Palaeosabella* is a monotypic genus in the sense of Art. 30c of the Rules, with *Vioa prisca* McCoy as its genotype. The fact that Clarke

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PLATE 2

Fig. 1. *Conchotrema tubulosa* Teichert, n. sp., infesting dorsal valve of *Spirifer* cf. *hardmanni* Foord. Byro series, 2 miles E. S E. of Survey Station R20, Wooramel River Western Australia. No. 8483. Nat. size. The outer shell layers are weathered and the tubes are exposed.

Fig 2. *Conchotrema tubulosa* Teichert, n sp., infesting dorsal valve of *Spirifer rostalinus* Hosking. Byro series, Wooramel River area, Western Australia No. 21270. X2.

Fig. 3. *Conchotrema tenuis* Teichert, n. sp., infesting dorsal valve of a *Spirifer* Wandagee series, Minilya River, west of Coolkilya Pool, North-West Division, Western Australia. No. 21321. X3.

had before him numerous specimens which he, possibly wrongly, identified with *Vioa prisca* can be of no taxonomic consequence, and no such species as "*Palaeosabella prisca* Clarke" exists. If it is found, as Fenton and Fenton suggest, that *Vioa prisca* and *Topsentia devonica* are congeneric, the name of *Palaeosabella* may become a synonym of *Topsentia*, the latter having page priority.

The name *Olkenbachia* Solle (1938), genotype *O. hirsuta* Solle appears to be a synonym of *Clionolithes* Clarke Solle was under the mistaken impression that Clarke in 1908 had selected *Vioa prisca* McCoy as genotype of *Clionolithes*. Recognizing the fact that the same species was also the genotype of *Palaeosabella* Clarke 1921, he claimed that the latter had to be suppressed as a synonym of *Clionolithes*, which in his opinion referred to worms. It seems that Solle had no knowledge of Fenton and Fenton's paper of 1932. He proposed the name *Olkenbachia* with *O. hirsuta* as genotype for a certain type of borings from the Devonian of Germany, and included in this genus *Clionolithes radicans* and *C. palmatus* from North America. Another genus, *Filuroda*, was established for *Clionolithes reptans* Clarke. It appears, therefore, that *Olkenbachia* is a subjective synonym of *Clionolithes* and that the following generic names are now available for borings of the types here under consideration:

Clionolithes Clarke 1908
 Genolectotype (Fenton and Fenton 1932) *C. radicans* Clarke 1908
 Synonym: *Olkenbachia* Solle 1938.
 Occurrence Devonian North America, Germany.

Filuroda Solle 1938
 Genotype: *Clionolithes reptans* Clarke 1908.
 Occurrence: Devonian. North America.

Topsentia Clarke 1921.
 Genomonotype *T. devonica* Clarke 1921
 Occurrence Devonian. North America
 Possible synonym: *Palaeosabella* Clarke 1921
  Genomonotype *Vioa prisca* McCoy 1855
  Occurrence: Silurian England.

It appears from our previous discussion that all these names refer to borings made by parasitic sponges, although some of them have at times been used for various types of worm borings,

and that, therefore, most of the objects described in various papers under various names as borings of parasitic worms are without any valid name. These include most of the borings referred to *Palaeosabella* and some of those referred to *Clionolithes* by Clarke in 1921, a Mississippian form, *Clionolithes canna*, as described by Price in 1916 and 1918, and the objects described in the present paper. *Caulostrepsis* Clarke (1908) seems to be the only name available for worm-made borings, but this name must be restricted to flattened, loop-shaped tubes as illustrated by Clarke in 1921 which cannot be easily confused with other forms.

It is, of course, necessary to remember that the objects to which all these generic names have been given constitute no more than what the palaeobotanist would call "form genera". We cannot be sure that all the borings known under one generic or specific name were the work of the same species or even genus of worms, particularly so, if objects from different parts of the world and of different age are involved. For practical purposes it is, however, desirable to name such objects in conformity with the Rules of Zoological Nomenclature.

DESCRIPTION OF SPECIES.

Conchotrema Teichert, n gen.

Derivation of name: *Konchē*, Gr. shell; *trema*, Gr. hole

This genus is intended to include borings in shells which consist of narrow tubes of generally less than 0.2 mm. diameter which communicate with the surface, but are otherwise completely buried in the shell. They are either straight, or only gently curved, and branching. Species may be distinguished by the thickness of the tubes and by the density of their distribution in the shell.

Genotype *Conchotrema tubulosa* Teichert, n. sp.

In addition to the genotype and the second species described below from the Permian of Western Australia the genus includes also *Clionolithes canna* Price from the Mississippian of North America. It seems probable that the Devonian of North America contains at least one undescribed species of the genus which is exemplified by an unnamed specimen of "*Palaeosabella*" from the Oriskany sandstone figured by Clarke in 1921, p. 98.

Whether or not specimens referred to "*Palaeosabella prisca*"

on p. 103 (figs. 95-103) of the same publication are also referable to our genus seems doubtful. The tubes in these specimens seem to be thicker, shorter, fewer and farther apart; also branching is seldom observed in them. It will probably be necessary to establish another new genus for these forms.

Conchotrema tubulosa Teichert n. sp.

Pl. 1, Figs. 1, 2; Pl 2, Figs 1, 2; Pl 3, Figs 2-4.

Description of holotype (no. 21318), Pl. 1 Fig. 1: The borings are found in the dorsal valve of a fairly large though poorly preserved productid which may belong to a species of either *Waagenoconcha* or *Aulosteges*. The inner side of the valve is exposed, while the outer side adheres to the matrix. The shell is penetrated by a network of fine tubes which are filled with limestone matrix. The width of the tubes varies between 0 2 and 0.3 mm. As a rule they are fairly straight for lengths up to 6 or 8 mm., side tubes may issue from a straight tube at intervals of from 1 to 3 mm., and eventually one tube may branch into one or more tubes or it may be bent in a gentle curve. Most of the tubes are entirely embedded in shell matter, others are open and run along the surface However, since it is evident that in places shell layers have been removed by weathering of the specimen, it seems certain that all the tubes were originally internal. No tubes are to be seen in cross-section and it seems therefore that the tubes cannot have entered the shell from inside of the valve. The tubes are fairly evenly distributed throughout the entire shell.

Occurrence of holotype: Nooncanbah series, Permian, 2 miles east of Christmas Creek Homestead, Kimberley Division.

Additional material· *Conchotrema tubulosa* is found in many large spiriferids and productids of the higher marine Permian beds of Western Australia. Only a few examples can be discussed here. Two dorsal valves of *Aulosteges baracoodensis* (nos. 21319, 21320) from the base of the Upper Ferruginous series, N. of Hill C, Grant Range, and from limestone at the base of Mt. Hardmann, Kimberley Division, are bored by tubes which show an arrangement similar to that of the holotype (Pl. 3 Fig. 4). In both these specimens there is, however, a tendency for the tubes in the anterior half of the shell to become arranged in parallel lines running in a radial direction. A similar arrangement of the tubes is characteristic in specimens described as "*Palaeosabella prisca*" from the

North American Devonian by Clarke in 1921 (p. 103) and also from the Devonian of Brazil (Clarke 1913, p. 177).

Along the Minilya River, west of Coolkilya Pool, there occur in the Wandagee series large numbers of a large productid, usually identified as *Taeniothaerus subquadratus*, which may attain a length of up to 10 cm. Many of these specimens are infested by *Conchotrema tubulosa* and it is almost invariably the very strongly convex ventral valve which is attacked (Pl. 1 Fig. 2). This is probably to be explained by the observation that this large productid had very long and strong spines so that the ventral valve was elevated above the sea floor to which it was attached by the spines. The sea-water carrying the larvae of the parasite had therefore free access to all parts of the ventral valve.

In the same area and the same strata, large species of *Spirifer* are also frequently infested by the same parasitic organism. In the spiriferids it is especially the dorsal valve which is infested. The dorsal valve of a large specimen of *Spirifer* cf. *hardmanni* Foord (no. 21323, 64 mm. long 84 mm. wide) has a well preserved shell which is pierced by numerous entrances of tubes (Pl. 2 Fig. 1). Near one of the cardinal angles about 25 small holes can be counted on an area of 1 square cm. If the ventral valve of one of these large Spirifers is infested at all the tubes are invariably restricted to a strip along the anterior margin of the shell.

Specimens of *Spirifer rostalinus* Hosking, another large spiriferid, from the Permian of the Wooramel River area show the same type of infestation as the spiriferids from the Minilya River. Specimens no. 8483 from 2 miles E.S.E. of Survey Station R20 has a dorsal valve which is everywhere penetrated by tubes which are similar to those of the holotype (Pl. 2 Fig. 2). No. 21270 from an unknown locality in the Wooramel area shows the parasitic tubes mainly confined to a strip of the dorsal valve close to the hinge-line. The tubes in this specimen are not quite as straight as in the holotype. They seem to be slightly finer and are more frequently curved and crossing over.

Smaller species seem to be less subject to attacks by *Conchotrema* although some specimens of *Spirifer* (usually known as "*Spiriferella*") *australasicus* have been found whose shells were penetrated by tubes of *Conchotrema tubulosa* (no. 21325), from the *Calceolispongia* stage of the Wandagee series of the

Minilya River. (Pl. 3 Fig. 3). The comparatively heavy hinge part of some of these specimens whose shell is up to 5 mm. thick is crossed by tubes lying in all directions.

With the exception of spiriferids and productids few shells seem to have been subjected to attack by the parasitic worm. So far only two valves of *Deltopecten* cf. *subquinquelineatus* (no. 21324) from the Permian of the Wooramel River area have been found which have been bored by *Conchotrema tubulosa*. (Pl. 3 Fig. 2). The tubes in these two shells are slightly narrower (0.15 to 0.2 mm. wide) than those of typical *Conchotrema tubulosa* and they are less straight

Remarks: *Conchotrema tubulosa* is closely similar to *Clionolithes canna* from the Pennsylvanian Conemaugh series of West Virginia Published pictures (Price, 1916, pl. 30 fig. 1; Clarke, 1921, fig. 91) leave little doubt that that species is a true *Conchotrema*. In 1916 (p. 668) Price described the species as follows:

"Fine tubules, freely branching and anastomosing, so as to form an irregular mat sometimes of several strands thickness, tubules varying slightly in thickness, from 0.16 to 0.25 mm. in diameter; seldom unbranched for as much as 2 mm. in length; branches straight, slightly curved, crescentic or a little sinuous."

In 1918 (p. 790) he added that " the tubules evidently were not raised upon the surface of the shell, but were completely buried within the shell substance and communicated at their ends with the surface." It will be seen that these conditions closely resemble those described in the Western Australian species. These Permian borings differ from the Pennsylvanian *Conchotrema canna* mainly in the fact that the tubes are less crowded in the former and cannot be said to form a "mat" as described by Price.

Judging from illustrations, *Conchotrema tubulosa* is also similar to a specimen from the Batesville sandstone (Mississippian) of Arkansas which Girty in 1915 (p. 38) described as a parasitic Bryozoan *Rhopalonaria ?* sp., but which resembles somewhat a worm of the *Conchotrema* type.

Some of our specimens also resemble rather closely an unnamed species of "*Palaeosabella*" from the Oriskany sandstone as figured by Clarke on p. 98 (1921).

Ecology of the species· If Conchotrema was a true parasite which infested living shells, one would expect to find the records

of its activities mainly on those parts of the shell that were free and not those that were in contact with the sea-bottom. It has already been pointed out that in spiriferids it is mostly the dorsal valve which is alone infested. The shells rested on the larger ventral valve which was probably partly embedded in the mud. In some instances it was found that the anterior margin of the ventral valve was attacked as well and it can be concluded that in such specimens the ventral valves were not wholly buried but that the anterior margin was free of the sediment.

In the small species *Spirifer australasicus* it was found that the umbonal region of the ventral valve was also infested by tubes and it may therefore be concluded that such small species were attached by the pedicle and elevated above the bottom of the sea so that the parasite had access to all parts of the shell.

The same is true in the case of some large productids of the type of *Taeniothaerus subquadratus* Since as has been mentioned it is invariably the ventral valve which is infested by the parasite it may be concluded that this species was supported by its large and strong spines which lifted the valve some distance above the bottom of the sea. The shell itself was thus completely surrounded by sea-water and the parasite in the larvae stage had easy access to the ventral valve which was thicker than the dorsal valve and, therefore, more desirable from the parasite's point of view.

It has already been observed that the parasite rarely attacked pelecypods. This also seems to be true for parasitic sponges: Solle (1938, p. 160) found that boring sponges in the German Devonian attacked brachiopods much more often than pelecypods.

Conchotrema tenuis Teichert, n. sp.

Plate 2 Fig 3

Description· Tubes not exceeding 0.1 mm. diameter, branching freely, seldom straight, but mostly curved or sinuous. The tubes are found in dorsal valves of spiriferids which they enter from the outside. The entrances of neighbouring tubes are usually not more than 0.2 to 0.3 mm. apart. The net work of the tubes is very much finer than in *Conchotrema tubulosa* and in *C. canna*.

Occurrence: So far this parasite has been found in valves of a large undescribed species of *Spirifer* (specimens 45 mm. long, 145 mm. wide along the hinge-line) in which the tubes are mainly restricted to the posterior half of the dorsal valve. Holotype: no. 21321, zone 19 of Wandagee series, syncline west of Coolkilya Pool, Minilya River. In another specimen from the same locality (no. 21190) a small area near the umbo of the ventral valve is also infested by the same type of tubes.

Gen. et sp. ind.

Plate 3 Fig. 1.

Another interesting parasite cannot yet be adequately described. Traces of its activities were found in a specimen of *Spirifer* cf. *byroensis* (no. 21330) from the lower half of the *Calceolispongia* stage of the Wandagee series (same general locality as foregoing species). It bored apparently few and large tubes. The specimen under consideration shows remnants of three tubes in its dorsal valve which are from 0.8 to 1 1 mm. wide. One tube can be followed in the shell for a distance of 13 mm. in which it is almost straight. Another tube starts about 5 mm. from the hinge line. Immediately after it has crossed the posterior margin of the dorsal area it turns at right angles and runs along the area parallel to the hinge line in the direction of the umbo. After a length of another 6 mm. however, it disappears in the interior of the shell probably continuing into the thickened shell matter of the hinge part in the vicinity of the umbo of the valve.

Clarke, in 1921, has described a number of specimens from the Oriskany sandstone of New York which bear considerable resemblance to our specimen. I refer in particular to the

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PLATE 3

Fig. 1. Tube of parasitic worm in the hinge part of a *Spirifer* shell. Wandagee series, Minilya River, west of Coolkilya Pool, North-West Division Western Australia No. 21330. X3

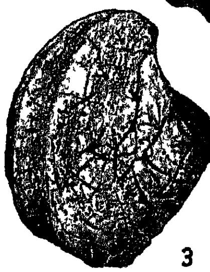
Fig 2 *Conchotrema tubulosa* Teichert n. sp, infesting valve of *Deltopecten* Byro series, Wooramel River area, Western Australia No 21324. X2.

Fig. 3 *Conchotrema tubulosa* Teichert, n. sp, infesting umbonal part of ventral valve of *Spirifer australasicus* Etheridge.

Fig. 4. *Conchotrema tubulosa* Teichert, n. sp, infesting dorsal valve of *Aulosteges baracoodensis* Etheridge Upper Ferruginous series, Grant Range, Kimberley Division, Western Australia. No 21319 X2.

1

2



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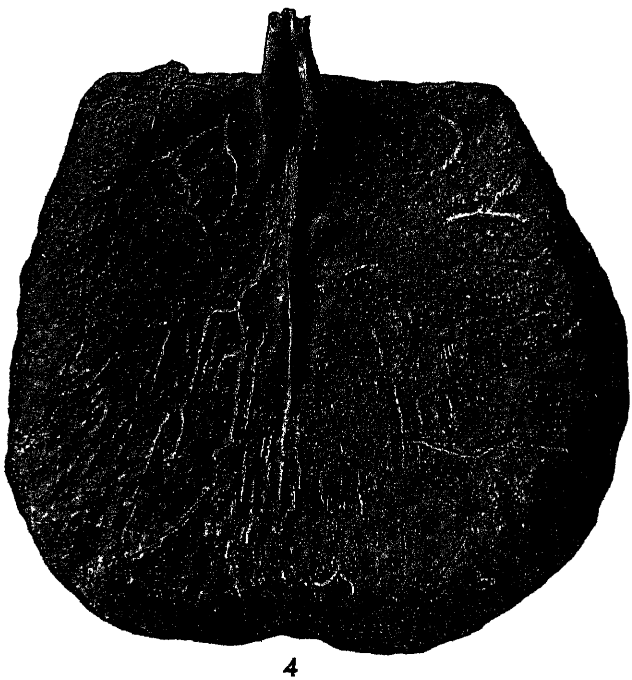

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stereograms reproduced by Clarke on pp. 92-97 and also to figs. 100 and 101 on p. 103. These pictures illustrate tubes which occur either solitary or in pairs and which have diameters between 1 and 2 mm. They are usually straight for some part of their length, bent in at least one place and sometimes curved in a hook-shaped fashion.

There is little doubt that these objects have nothing to do either with *Conchotrema* or *Caulostrepsis* and that a new genus should be erected for them which should probably also include the specimen from Western Australia described above. However, the description of such a genus is better left to one who has access to Clarke's original specimens

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RING STRUCTURES AT MAUNA KEA, HAWAII.

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ABSTRACT Besides the radial rift zones characteristic of Hawaiian volcanoes, Mauna Kea also shows arcuate alignments of cinder cones along lines concentric to the eruptive axis of the volcano. These indicate the existence of arcuate fissures and groups of fissures, occupied beneath the surface by ring dikes or cone sheets. The arcuate alignment of vents appears to be the result of intersection of shallow-seated radial fissures with the arcuate intrusions at depth

INTRODUCTION.

CONCENTRIC structures, such as ring dikes, cone sheets, and cauldron subsidences, are common features of many volcanic districts. The classic examples occur in Scotland, especially among the Tertiary volcanics, but also in more ancient rocks.[2] Examples also have been found in North America,[3] and elsewhere. At volcanoes which are too little dissected to reveal the internal structure, the existence of concentric intrusions at depth is implied by the arcuate alignment of minor vents on the flanks of the mountain,[4] and the large calderas which occur at many volcanoes are the result of subsidence along concentric fissures.

In Hawaii, calderas formed by the subsidence of roughly circular segments of the summits of the great volcanoes have

[1] Published by permission of the Director, Geological Survey, U. S Department of the Interior.

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long been recognized. Although these subsidences have suggested the probable existence at depth of ring dikes, and possibly cone sheets, direct evidence of those features has not until now been recognized. It is the purpose of the present paper to offer recently discovered evidence of their existence at Mauna Kea. Unpublished notes by A. E. Jones in the possession of C. K. Wentworth, written about 1935, appear to indicate that he suspected the existence of arcuate structures at Mauna Kea. R. H. Finch, in an unpublished report to the superintendent of Hawaii National Park, dated December 6, 1941, also noted that cinder cones on Mauna Kea might be aligned along both radial and concentric rifts. As a background for the discussion of the structural features, the general geology of Mauna Kea will be briefly summarized.

R. H. Finch, T. A. Jaggar, H. T. Stearns, and C. K. Wentworth have kindly criticized the manuscript. James Y. Nitta prepared the figure.

GENERAL GEOLOGY OF MAUNA KEA.

Mauna Kea, on the island of Hawaii, is the highest peak in the Hawaiian Islands. A large cinder cone at the summit reaches an altitude of 13,784 feet above sea level. On the north the lavas of Mauna Kea are banked against the older and smaller Kohala Volcano (Text Fig. 1), and to some extent interbedded with the latest lavas of the Kohala Volcano.[5] On the south they are overlapped by late lavas of Mauna Loa, but deflection of late flows of Mauna Kea eastward and westward along the depression between the two mountains indicates that the northern slope of Mauna Loa must already have been built nearly to its present position at the time they were erupted. Mauna Kea and Mauna Loa must have grown to a large extent simultaneously, and their lavas must be interfingered at depth. A similar relationship probably exists between the lavas of Mauna Kea and Hualalai.

The volcanic rocks of Mauna Kea are divided in Text Fig. 1 into two groups, named respectively the Hamakua and Laupahoehoe volcanic series. The Hamakua volcanic series is named for its exposures along the Hamakua coast, northwest of Hilo, where it is well exposed in sea cliffs and in the walls of large

[5] Stearns, H T, and Macdonald, G A.· Geology and ground water resources of the island of Hawaii, Hawaii Div of Hydrography, Bull. 8, in preparation

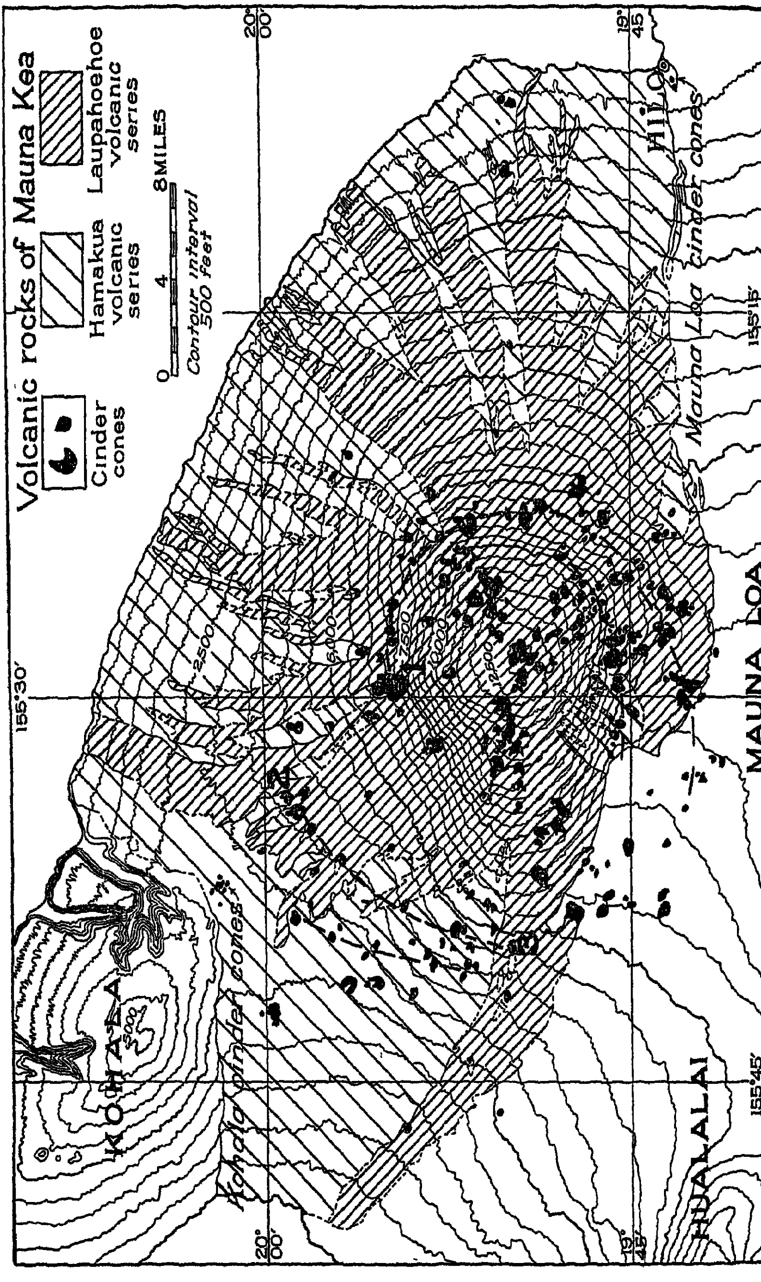

Fig. 1. Geologic map of Mauna Kea, Hawaii, showing arrangement of cinder cones along radial and concentric fractures.

gulches. Its greatest exposed thickness is 650 feet, but its thickness below sea level is many thousands of feet. The Laupahoehoe volcanic series is named for its exposures at Laupahoehoe peninsula, where a typical andesite flow has built a lava delta. At its type locality lava of the Laupahoehoe volcanic series is separated from the rocks of the older Hamakua volcanic series by a profound erosional unconformity. Erosional unconformities of lesser magnitude separate the two volcanic series at other localities, but in still other places there is no sharp separation. Volcanism was essentially continuous from one to the other. Around the periphery of the mountain many of the lava tongues of the Lapahoehoe volcanic series are only one or two flows in thickness. On the upper flanks of the mountain erosion has in general been too slight to expose the base of the Laupahoehoe volcanic series, but the presence of a large kipuka of the Hamakua volcanic series extending up the southern slope to about 10,000 feet altitude indicates that the thickness on the outer slopes of the mountain probably nowhere exceeds a few hundred feet, and in many places may be measurable in tens of feet However, if a caldera formerly existed, as appears probable, and was filled by the Laupahoehoe volcanic materials, the series may reach a thickness of two or three thousand feet.

The rocks of the Hamakua volcanic series consist largely of olivine basalts, representing the undifferentiated magma of the Hawaiian province. A few thin ash beds are intercalated with the lavas, but for the most part pyroclastic debris forms only a small proportion of the whole. The lavas were erupted in a highly fluid condition, and spread out as thin flows far from their vents, building a broad shield volcano. In the upper part of the Hamakua volcanic series, high on the southern slopes of the volcano, there are exposed, however, thick deposits of explosion debris composed of blocks of olivine basalt and picritic basalt in a matrix of vitric-crystal tuff.[5a] If such deposits are abundant in the upper part of the cone, below the levels revealed by the shallow erosional dissection, they together with the greater abundance of eruptions at and near the central eruptive axis probably account for the steepness of the upper slopes of the cone, which have an average inclination of about 16° in contrast to 5° on the lower slopes.

[5a] Stearns, H. T: Glaciation of Mauna Kea, in preparation.

Gradually, as the frequency of eruption decreased and the magma chamber feeding the volcano cooled, differentiation brought about important changes in the composition of the erupted lavas. Interbedded with the olivine basalts in the upper part of the Hamakua volcanic series there are many flows of picritic basalt and andesite. The picritic basalts are rich in phenocrysts of olivine and augite, and are believed to have formed by the settling of intratelluric phenocrysts from upper to lower portions of the magma column. The andesites are believed to represent the upper part of the magma column, impoverished in the constituents of the sunken phenocrysts.

The Laupahoehoe volcanic series contrasts with the earlier rocks in consisting very largely of andesites, with less abundant olivine basalts. Picritic basalts are entirely absent. The andesites in general were erupted in a more viscous condition than the earlier lavas, with the production of greater quantities of pyroclastic material Locally, small viscous domes were formed by the accumulation of lava around vents.

Except in a small wind-swept area southwest of Waimea, on the northwest side of the mountain, the surface of the lavas of the Hamakua volcanic series is buried beneath a cover of yellow to reddish-brown ash, correlative in age with at least a part of the Pahala ash on Mauna Loa.[6] This ash is 15 feet thick near Hilo, gradually decreasing in thickness northwestward Near Kukaiau, 25 miles northwest of Hilo, it is only 5 to 6 feet thick, and in the saddle between Mauna Kea and Kohala its greatest depth is 4 to 5 feet. Where not influenced by outside factors, its thickness increases up the mountain. At any locality, the maximum thickness is present only where the accumulation of ash has not been interrupted by lava flows. Its distribution and variation in thickness indicate clearly that most of the ash came from cones on Mauna Kea, although there must have been small additions from such other neighboring sources as the northeast rift zone of Mauna Loa Far from being a good time marker, the Pahala ash at its places of maximum thickness represents continuous accumulation from late Hamakua time to the present. A smaller amount of ash is present also on many flows of the Laupahoehoe volcanic

[6] Stearns, H T, and Clark, W O: 1930, Geology and water resources of the Kau District, Hawaii, U S Geol Survey Water Supply Paper 616, p. 66-88

series, equivalent in age to the upper part of the ash on lavas of the Hamakua volcanic series.

Near the end of its eruptive history, the summit of Mauna Kea was buried beneath glacial ice. A few small lava flows are later than the glacial drift, and other flows at lower altitudes appear to be of about the same age. These late flows have been arbitrarily separated from the rest of the Laupahoehoe volcanic series. All are andesites.

CONCENTRIC STRUCTURES.

Hawaiian volcanoes are characterized by zones of fracturing that extend outward from the summit of the mountain These are known as rift zones. There are generally three of these rift zones, the mountain being divided by them into three more or less equal wedge-shaped segments. One of the rift zones is, however, generally less prominent than the other two. The rift zones are marked at the surface by rows of cinder and spatter cones, and at depth by innumerable roughly parallel dikes.

The structure of Hawaiian volcanoes, as expressed in the rift zones, is thus typically radial. This radial arrangement of rifts is found on Mauna Kea, one rift zone trending nearly westward from the summit, another northeastward and the third southeastward. They are clearly shown in Text Fig. 1 by the alignments of cinder cones. The western rift appears to be prolonged eastward beyond the summit, giving vent to a few eruptions low on the eastern flank of the mountain. Other radial eruptive fissures lie between the rift zones, but the greater abundance of vents within the rift zones is obvious.

In addition to the radial structure, there is present on Mauna Kea an arrangement of the cinder cones along lines concentric to the eruptive axis of the volcano. In the field, one of the most prominent concentric alignments is the ring of cones that encircles the summit platform (Plate 1), although owing to the small scale, it is not very conspicuous on the map. This series of cones, including Poliahu Cone, Summit Cone, Goodrich Cone, Waiau Cone, and two unnamed cones between Poliahu and Summit Cones, forms three sides of a roughly horseshoe-shaped basin about a mile across. All of the cones are andesitic.

Other arcuate alignments of cones are indicated in Text Fig 1 Two prominent arcs occur on the southern slope. A less definite alignment extends half way around the mountain

from the Humuula Saddle on the south along the eastern and northern flanks to Kaluamakani Cone (1).[7] The extension of this alignment throughout the entire arc of 200° may not be justified, but segments of it at least are definite.

A very definite arcuate alignment of cones extends from Puu Io (2) on the northwestern slope of Mauna Kea, southwestward to Puu Kanalopakanui (3), a distance of 13 miles, and 60° of arc. These cones are of late Hamakua age, and all of them are built of picritic basalt. At many of them loose well-formed crystals of augite and olivine can be collected. Another nearly parallel line of cones lies two to three miles to the west.

In some places the arrangement of the cones appears to indicate two or more parallel arcuate alignments. Moreover, along some of the arcs the cones appear to be of somewhat different age.

The arcuate alignments of cones appear to indicate the existence of concentric arcuate fissures, or groups of fissures, which served as loci for the rise of magma from the underlying magma chamber. Intrusion of magma into such fissures would result in the formation at depth of ring dikes or cone sheets, depending on the inclination of the fissure. There is no definite indication at Mauna Kea as to whether the dikes dip inward, as cone sheets, or are vertical or steeply outward-dipping, in the manner of ring dikes. The known occurrence at Hawaiian volcanoes of cauldron subsidence in the formation of summit calderas suggests, but by no means proves, that the arcuate intrusives are ring dikes. On the other hand, there is no detectable evidence of collapse of the upper part of Mauna Kea. Although a caldera probably once occupied the top of the mountain, it has been buried and completely hidden by later lava flows and pyroclastic materials. Still another line of evidence suggesting that the underlying arcuate intrusive bodies are probably ring dikes is the apparent long persistence of surficial activity along some of the arcs. Cone sheets are typically thin, and would be expected to cool relatively quickly, whereas many ring dikes are thick and might remain uncrystallized for considerable periods, during which they could supply magma for surficial eruptions.

Although the cones are aligned along definite arcs, no example

[7] The numbers in parentheses refer to the numbered localities in text Figure 1.

Summit of Mauna Kea from the north-northeast, showing the arrangement of cones along an arcuate fracture Starting at the right and proceeding in a clockwise direction, the cones are Poliahu, two unnamed cones, Summit, Goodrich, and Waiau Cones Photo by U S Army Air Corps

has been found in which the surficial crack along which eruption occurred was parallel to the arc. At many places there is no definite indication of the course of the eruptive crack, but at many others the alignment of pits or the arrangement of the group of cones shows conclusively that the crack was radial with respect to the summit of the mountain. Thus it appears that although the feeding body at depth was arcuate in form, the shallower-seated fissures along which eruption occurred were radial.

From a study of a geological relief model of Mount Etna, it appears that there are present at that volcano features closely resembling those at Mauna Kea. Prominent radial rift zones, and also distinct concentric alignments of cinder cones can be distinguished. A concentric alignment of parasitic cones has been recognized also on Fuji Volcano. Fujiwhara[8] believes that the parasitic cones of Fuji are arranged along logarithmic spiral fractures, caused by thrust along the volcanic axis. The spiral fractures he compares with spiral flow figures produced on the polished surface of a steel plate, when it is punched with a cylindrical steel rod. A similar tendency toward spiral arrangement of the cones appears probable on Mauna Kea, (Text Fig. 1), but it is not sufficiently definite to be asserted as a fact.

In conclusion, cinder cones on Mauna Kea show both radial and concentric alignments, indicating both radial and concentric fissures that acted as conduits along which the magma rose from depth. The radial fissures are most numerous in three zones, which constitute the radial rift zones typical of Hawaiian volcanoes. Many radial fissures occur outside of these principal rift zones, however. Vents are especially numerous at the intersection of the radial rift zones with the arcuate lines. Magma rising along the arcuate fissures probably formed ring dikes at depth, but the arcuate fissures seldom, if ever, conducted the magma to the surface. The shallow fissures that were sufficiently open to permit the rise of magma to the surface were radial, the arcuate arrangement of vents being the result of the intersection at unknown depth of the radial fissures with the arcuate intrusions.

[8] Fujiwhara, S : 1934, On the spiral arrangement of the parasitic cones of Huzi (Fuji) Volcano, Fifth Pacific Sci. Cong Proc, vol. 3, pp. 2265-2270.

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DISCUSSION.

EARLY PERMIAN ROCKS OF SOUTHERN PERU AND BOLIVIA.

This is a preliminary note to announce that a large part, at least, of the "Carboniferous" beds, long known in the region about Lake Titicaca, are of Early Permian (i.e., Wolfcamp) age. A report on the stratigraphy and on the fusuline faunas is in preparation and will be published in the near future.

While gathering from these beds the material for his excellent monograph, "Les Brachiopodes du Carbonifère supérieur de Bolivie," Dr. Ramon Kozlowski made a fine collection of fusulines which shortly before the outbreak of the war were sent to Dunbar for study. Sections were made and illustrations and descriptions of a score of species were prepared, but meanwhile communication with Doctor Kozlowski in Warsaw was broken and it was impossible to secure from him a much needed stratigraphic summary. Publication was therefore delayed.

During the year 1944, Newell had an opportunity to make reconnaissance studies of these late Paleozoic deposits over a large area in southern Peru and northern Bolivia and to study and measure three fine sections and make zonal collections of the fossils. The fusulines were sent to Dunbar and the stratigraphic studies are now being prepared for publication by Newell. Kozlowski's fossils can now be placed in these sections.

These late Paleozoic deposits rest upon Middle Devonian and are overlain by Lower Cretaceous and Lower Cenozoic deposits and are preserved only in synclines of limited areal extent. The most complete section measured is in the Munani area in the headwaters of Río Munani about 50 kilometers north of Lake Titicaca, and it has a thickness of over 5700 feet. The section on Peninsula Copacabana in Lake Titicaca is only about 2400 feet thick.

Fusulines occurring in the middle and upper part of these sections are all clearly of Wolfcamp age. They include at least three species of *Pseudoschwagerina* along with a few species of *Schwagerina* and several of *Triticites*. Among these is the largest species of *Pseudoschwagerina* yet known.

Since the lowest zone of fusulines was found about 1800 feet above the base of the section in the Munani area and about 1100 feet above its base in the Capacabana area, it is possible that the Pennsylvanian system is represented below the Permian, but no evidence therefore is now known; the horizons from which the well known "Upper Carboniferous" fossils have come (i.e., the *Spirifer condor* zone) are shown by the fusulines to be of Wolfcamp age, as R. E. King correctly inferred in 1930 (p. 36) from a study of the brachiopods described by Kozlowski.

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SCIENTIFIC INTELLIGENCE

MINERALOGY.

Dana's System of Mineralogy; by CHARLES PALACHE, HARRY BERMAN and CLIFFORD FRONDEL. Seventh Edition Vol. I, pp. xi+834 (6×9). New York, 1944 (John Wiley and Sons, $10.00).—The appearance of a new edition of Dana's System is a great event, eagerly awaited. Fifty-three years have passed since the Sixth Edition was published in 1892 and thirty years since the publication of the third and last appendix to that edition. During this long interval, the judgment that "mineralogy is a completed science" was pronounced and was promptly refuted by the revolutionary discovery of the diffraction of x-rays by crystals. The new knowledge of the structure of crystalline matter has profoundly altered some of the most fundamental concepts of mineralogy. It is not surprising, therefore, to find many changes in the new edition, and it is gratifying that the old concepts have not been indiscriminately swept away, but rather integrated into the modern framework of the science.

In their achievement of proper balance, the authors of the Seventh Edition have maintained the standards set in the previous editions. The First Edition, published in 1837 by J. D. Dana (in his twenty-fourth year!) and the Second Edition published in 1844 were based on the so-called natural history system of classification. but Dana, in the Third Edition in 1850, indicated dissatisfaction with this system. Only four years later in the Fourth Edition he abandoned it completely in favor of a chemical classification. The Fifth Edition in 1868 was marked by advances in systematization, particularly in the recognition of the close relationships among minerals that are today grouped together. The Sixth Edition was published in 1892 by E. S. Dana after ten years of labor and is undoubtedly one of the most remarkable critical compilations ever written. Essentially the work of one man, it would be noteworthy merely for the almost complete absence of error, but it is great because its author combined nicety of judgment on controversial points with real insight with respect to broad relationships.

The first of the projected three volumes of the Seventh Edition continues the tradition of sound scholarship and critical selection. It is not a very difficult task, though a tedious one, to assemble all the data of mineralogy. The real test of skill and judgment is the reduction of a huge mass of data to a concise, yet complete and coherent account, and that test has been met most successfully by the authors of the Seventh Edition. Volume I shows an expan-

sion of perhaps 20 to 30 per cent over the corresponding sections of the Sixth Edition, but careful reading of the text indicates that this expansion was held to a minimum by rigid selection and by economy of words throughout.

Futhermore, the authors have performed an invaluable service to mineralogy by their emphasis on unsolved problems and needed research. The new Dana should be a source book of research problems for a long time. That is as it should be; one of the main objectives of any compilation in science should be to guide the way to research that makes the compilation obsolete.

In summary, though this Edition is not "by Dana," it is worthy of the Dana name. It is an accomplishment of such magnitude that the reviewer is somewhat hesitant to discuss points, relatively unimportant, on which he disagrees with the authors. However, discussion of Volume I may be helpful in the preparation of Volumes II and III, which probably will not be ready for some years. Accordingly, differences in viewpoints are mentioned in the following discussion of the details of the Seventh Edition.

The classification remains chemical, and Volume I shows relatively few major changes. Eight classes are included. (1) Native elements; (2) Sulfides; (3) Sulfosalts; (4) Simple oxides; (5) Oxides containing uranium, thorium and zirconium; (6) Hydroxides and oxides containing hydroxyl; (7) Multiple oxides; (8) Multiple oxides containing columbium, tantalum and titanium. The principal changes from the Sixth Edition are the division of the oxides into five classes, the inclusion of the so-called titanates, columbates and uranates with the oxides, and the classification of quartz and the other forms of silica with the silicates rather than with the oxides. The second and third of these changes will require some mental adjustments by most readers, but are logical in the light of modern knowledge of atomic structure and help to make the presentation better integrated. Each class is subdivided into types, the order of presentation being that of decreasing cation to anion ratio. Within the types, numerous mineral groups are recognized. A new and laudable feature is the treatment of complete isomorphous series as single units.

The consecutive numbering system of the Sixth Edition has been replaced by a more complex system, which has, however, the advantage of elasticity and which allows new minerals to be numbered according to their proper positions. The change poses a serious problem to curators of the many mineral collections that are arranged according to the system of the Sixth Edition. The new numbering system should be an aid in keeping collections properly arranged, but the initial labor of rearrangement will be very great, perhaps prohibitively so. The following minerals appear to the

reviewer to have been misplaced in the classification on the basis of cation to anion ratio· the tetradymite group, nagyagite, bismite, sillenite, and psilomelane.

The new edition has followed the principles of nomenclature that were recommended by the Second Committee on Nomenclature of the Mineralogical Society of America (Am. Mineral. 21, 188 (1936)) and formally adopted by the Society (Am. Mineral. 24, 176 (1939)). It is to be hoped that the combined prestige of Dana and the Society will persuade all mineralogists to conform to these principles. Curiously enough, the authors of the Seventh Edition have written an account (pp. 46-47) in which the rules of nomenclature actually adopted by the Society are confused in part with some of the earlier suggestions of the First Committee rejected by the Society, so that the reader is left with the misleading impression that the nomenclature of the Seventh Edition represents only the authors' personal choice.

The most important change in nomenclature is the adoption of W. T. Schaller's proposal to replace with uniform adjectival modifiers the varietal names based on minor isomorphous replacements. This proposal has been objected to by many at first sight as artificial and untraditional, but a fair trial has convinced many American mineralogists of its advantages. These are evident as never before on inspection of Volume I of the Seventh Edition. To cite a single example, the use of suitable adjectival modifiers with the two names tetrahedrite and tennantite makes it possible to discard at least nine special names for varieties. General adoption of this method of naming varieties is the most promising means of preventing the science from being buried under the growing burden of useless and unnecessary names. The reviewer guesses that the indexes of the Seventh Edition will, when completed, contain over 10,000 entries, of which probably three-fourths will be names not needed by the science. Clearly it behooves anyone about to propose a new name to think twice as to whether or not it will serve a useful purpose.

The authors of the Seventh Edition have departed from customary American practice by using the symbols nX, nY, nZ, nO and nE in place of the more common α, β, γ, ω and ϵ for the indices of refraction The symbols used are unambiguous and probably will not cause any difficulty. They also have the advantage of being easy to type. It is to be regretted that three sets of symbols for indices of refraction are in use in the United States. Agreement on the use of one set should be sought.

A minor criticism of the nomenclature is that Russian proper names have not been handled systematically or consistently.

The crystal symmetry class is given for each mineral in the

notation of Groth as modified by Rogers. The axial ratio is listed for both the direct and the reciprocal ratios. In addition, elements other than those adopted are listed in the references with the transformation formulas to the accepted elements. The most common forms are listed with calculated angles; rare and uncertain forms are listed in the references. The angles are not the direct interfacial angles as in the Sixth Edition, but are the polar angles of the faces in terms of the gnomonic projection for the possible settings of each crystal on the goniometer.

The presentation is designed to serve the needs of crystallographers and will be invaluable to them. Presumably, lack of space did not permit inclusion of the direct interfacial angles. Their omission will diminish the utility of Dana to many who are unfamiliar with the two-circle goniometer, but who may have occasion to measure an interfacial angle. To be sure, the Introduction gives the necessary calculations in some detail, but it seems probable that most users of Dana will prefer to turn to the angles listed in the Sixth Edition, when possible.

The x-ray crystallographic data are limited to the space group. given in the Hermann-Mauguin notation, the unit cell lengths and the atomic content of the unit cell. Some hitherto unpublished information is given. Discussion of the details of the structures is not attempted except for brief statements of features common to members of groups or types. X-ray powder data are not included.

In addition to conventional statements of habit and twinning, there are listed under the new subheading Oriented Growth the species with which intergrowths have been observed and also the positions of mutual orientation. This is a welcome and most useful addition.

The crystal drawings were well chosen and carefully prepared. Unfortunately they are not numbered, which will make reference to them difficult when more than one are printed on a single page.

The physical properties are given much as in the Sixth Edition, but data on such properties as thermal expansion, thermoelectricity, magnetic properties, gliding planes, and melting points have been included when available. The noticeable paucity of such information should be a challenge to mineralogists. The data for specific gravities are notably improved by the inclusion of many previously unpublished determinations made by means of the Berman microbalance.

Optical data given for opaque minerals in reflected light include color, anisotropy, and reflection percentages for various wave lengths of light. Etch reactions and microchemical tests have been omitted For the non-opaque minerals, the indices of refractions are listed for several wave lengths of light and, for the few min-

erals for which such information is available, at various temperatures as well. It is to hoped that Volumes II and III will utilize graphical presentation of the variations of optical properties for isomorphous series.

The section on chemistry lists the formula, with a discussion of isomorphous substitutions and the observed limits of substitution. In general, the isomorphous substitutions treated in this volume are simple in type, and it is only in Class 8 (Multiple oxides containing columbium, tantalum, and titanium) that the modern theory of isomorphous replacement as a function of ionic radius is very evident. The authors have achieved some noteworthy simplifications in the treatment of this extremely complex class. Throughout the volume, the analyses listed have been selected to illustrate the range in composition. Not as many are given as would be desirable, presumably because of space limitations. The qualitative tests, treated very briefly, are elementary in nature.

The authors are to be congratulated particularly for the section on occurrences. For each species, a general statement of the types of occurrences is given, with emphasis on paragenesis and on mineral associations. These are also given for each locality in the detailed list of occurrences, which is therefore much more than a catalogue of place names. Economic geologists should especially welcome this presentation. Great care has obviously been taken in listing the names of foreign localities, in which there are practically no errors.

Features that have been retained much as in the Sixth Edition include discussions for each mineral of its alteration products, the derivation of its name, and a complete synonymy. The section headed Artificial has been expanded to include not only the reported methods of synthesis, but also references to the physico-chemical studies of systems bearing on the stability relations of the mineral. Special features are a brief, but excellent account of Radioactivity by J. P. Marble, and a section summarizing our knowledge of Meteorites.

Another valuable feature retained from the Sixth Edition is a comprehensive list of journals in which mineralogical papers appear, with much useful information on dates of publication, serial numbers and indexes. In addition, the list of independent reference works has been revised and brought up to date. The citations to the literature, collected under the heading References, have been selected with discrimination and will be indispensable to mineralogists. Under this heading are also given concise discussions of disputed points, notes on recorded data not in agreement with those accepted, previously unpublished data and much similar material of great

value. The index, key to the usability of any compilation, is complete and accurate.

The publishers, John Wiley and Sons, have celebrated the centennial of their first connection with Dana by producing a volume of fine appearance despite the restrictions and difficulties caused by the war. The type is clear and easy to read. The paper is of good quality. War-time restrictions are reflected in the narrow margins and the close spacing of lines, which make it difficult to insert new data or to correct misprints. The latter are fortunately minor and will be easily corrected in the next printing.

Because the Seventh Edition will, like the Sixth, be the "mineralogists' Bible" for many years, it is of interest to note the changes in overall emphasis that are particularly noticeable. As might have been expected, the present-day conceptions of crystal-chemistry are fundamental in the presentation. The trend towards specialization is reflected, particularly in the presentation of crystallographic data. Perhaps most important of all is the emphasis on genetic mineralogy, which is in accord with the growing interest in minerals, not solely as independent entities, but also as parts of the assemblages in which they occur.

Volume I has special significance as a living memorial to Harry Berman, whose tragic death while engaged in war work occurred only a few weeks after the publication of the first part of the great work he and his colleagues had undertaken. His skill, energy and devoted persistence played a major part in the completion of Volume I, and his death is a staggering loss. All will join in the hope that Professor Palache and Doctor Frondel may soon be able to resume their work on the System and carry it through to completion.

MICHAEL FLEISCHER.

PUBLICATIONS RECENTLY RECEIVED.

Washington Geological Survey Reports of Investigations as follows: No 7. Character and Tonnage of the Turk Magnesite Deposit; by W A. G Bennett; price $25 No 8. The Buckhorn Iron Deposits of Okanogan County, Washington; by W. A. Broughton; price $25 No 9 Inventory of Mineral Properties in Chelan County, Washington; by M. T Huntting; price $25. No. 10. The Blewett Iron Deposit Chelan County, Washington; by W. A Broughton; price $25. No. 11 Stratigraphic Aspects of the Blewett-Cle Elum Iron Ore Zone Chelan and Kittitas Counties. Washington; by R L Lupher; price $25. No. 12. Economic Aspects of the Blewett-Cle Elum Iron Ore Zone Chelan and Kittitas Counties, Washington; by W. A. Broughton, price $25. No. 13. Dolomite Resources of Washington. Part I. Preliminary Report on Okanogan, Lincoln, and Stevens Counties, by W. A. G. Bennett; price $.25, Pullman 1944.

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FOREWORD.

(TO THE SYMPOSIUM ON LOESS, 1944.)

SOIL and water are the two most important natural resources of the agricultural state of Nebraska and the adjacent territory. Hence the selection of Loess from which most Nebraska soils are derived as a topic for a Symposium at the Earth Science Section of the Nebraska Academy of Science in 1944, under the co-chairmanship of C. B. Schultz and M. K. Elias.

The organization of the Symposium on loess provided an opportunity for an invitation of out-of-state scientists for the purpose of a more complete review and discussion of the Loess problems. It was also a gesture of appreciation of their work and of the willingness for coöperative researches by the Nebraska scientists. Thus we secured participation of the following colleagues: Kirk Bryan of Harvard University, who studied for many years the Pleistocene and late Tertiary physiography and geology of both southern and northern ends of the eastern slopes of the Rocky Mountains in the United States; John C. Frye, Assistant State Geologist of Kansas; and Miss Ada Swineford, graduate of the University of Chicago and member of the Kansas Geological Survey. The coming to the meeting of these, as well as other Kansas geologists and paleontologists resulted not only in profitable discussions on loess at and outside the meeting, but also strengthened friendly coöperation and helped understanding and formulation of the current problems involved in the study of the whole province of the eastern slope of the Rocky Mountains and the adjacent plains.

The importance of international cooperation in scientific studies was acknowledged by invitation of V. A. Obruchev, the leading European specialist on Loess and academician of the Academy of Sciences of the USSR. The Russian Ambassador, Andrey Gromyko, promptly forwarded the invitation to Moscow and Obruchev responded to it by sending a 1400 word paper cablegrammed to Elias at Lincoln, by the Russian Society of Cultural Relations at Moscow.

The following papers were read at the meeting:

1. Loess and Its Economic Importance, by M. K. Elias.
2. Pleistocene Loess Deposits of the Great Plains, by C B. Schultz and T. M. Stout.
3. Glacial versus Desert Origin of Loess, by Kirk Bryan.
4. Mechanical Analysis of Wind-blown Dust and of Loess, by Ada Swineford and John C. Frye.
5. Accumulation of Dust in Relation to Herbaceous Vegetation, by J. E. Weaver.
6. Need of Further Researches on Loess, by G E. Condra.
7. Loess Types and Their Origin, by V. A. Obruchev.
8. Significance of Loess in Classification of Soils, by James Thorp.
9. Sequence of Soil Profiles in Loess, by B. H. Williams.
10. Infiltration into Certain Loess Soils, by F. L. Duley.
11. Characteristics and Uses of Loess in Highway Construction, by R. E. Bollen.
12. Observations on the Properties of Loess in Engineering Structures, by W. I. Watkins.

The discussions which followed presentations of the papers of the Symposium were recorded at the meeting by stenographers. After being edited and submitted for approval to their respective authors, their final texts are here being added at the end of the papers to which they largely or entirely pertain.

Although the Symposium has not been organized for the explicit purpose of solving one way or another the problem of loess origin, all contributors expressed or indicated their adherence to the eolian theory, and the discussions were devoted chiefly to evaluation of the probable sources of dust, and the mechanism of its accumulation in formation of loess. The intimate relationship between geological and pedological processes which are involved in the origin of loess were clearly recognized by all, and indebtedness to both geologists and soil scientists for understanding of loess and its properties, which are so necessary for its utilization in engineering constructions. was acknowledged in contributions devoted to its economic use.

The need for further researches on loess and the character of problems involved have been discussed, and some plans for their organization were formulated at the Meeting and subsequent to it.

M. K. ELIAS.

LOESS AND ITS ECONOMIC IMPORTANCE.

M. K. ELIAS.

ABSTRACT The purpose of the symposium on loess is to present the status of our knowledge on it, particularly in regard to Nebraska

Fertility of loess, because of which it is frequently miscalled soil, is its most valuable property for mankind. The principal wheat producing regions of the world roughly coincide with the areas of distribution of this "golden earth" of agriculture Where it mantles the ground the loess and the soils developed from it are the principal or, frequently, the only readily available material for roads, dams, and other engineering constructions.

In spite of many published studies on loess much remains to be learned about its origin, distribution, and best utilization.

THIS symposium on loess has for its purpose the taking stock of the present knowledge of loess, its origin, and distribution, its relation to the soils, and its use in engineering construction.

In the genesis of loess some soil processes must have played a part, because in the course of its accumulation the surfaces of the successive layers were exposed to atmospheric agents, until covered and buried under succeeding layers deposited upon them. On the other hand, on the subsequently exposed surfaces of loess the modern soils have been developed.

In Nebraska loess and loess-like deposits are by far the most widespread among the outcropping formations and the richest soils of the state are those developed from loess. In many parts of the state loess is the only readily available natural material for construction of roads and earth dams.

Ever since the thick deposits of loess originated they have been subject to erosion and redeposition by water and wind. Great quantities of washed-out loess were carried by running waters, and the suspended particles were dropped in backwaters along the valleys, where they, together with other sediments, built the fertile bottom lands.

Along the higher slopes of the valleys quantities of loess were sometimes gradually and sometimes suddenly slumping from higher to lower elevations, and thick loess muds were also creeping down. On their way down they were occasionally mixed with variable rock fragments. The valley-slope loess, thus redeposited, frequently shows rough stratification due to the interbedded layers in which it is mixed with rubble and other débris.

Some geologists and civil engineers refer to loess as soil. Strictly speaking this is erroneous because the true loess is but mother-rock on which soil is developed. However, typical loess is comparable to the good, productive soils in its earthy constitution, friability, porosity, and fertility. Loess is made of pulverized rocks, a ready made natural fine-grained mixture which has friability and porosity comparable to that in soils, and contains most of the soluble mineral compounds essential for growth of grains and other staple crops.

If all the black humus top zones of our tillable loess-soils were stripped from them, for instance by an extremely extensive blowout due to drought, and the primeval yellow loess under them exposed throughout our land—it could be put to tillage at once, and would probably produce a normal crop and, in some cases, where the top soil is impoverished, even better than normal crop, providing there would be sufficient amount of moisture in the ground. This statement should not be understood as minimizing the importance of erosion control of soils and of agronomic practices aimed at maintenances and improvement of its fertility,—the importance of these cannot be over-emphasized.

Typical loess contains an average of about 20 per cent of feldspar in a more or less advanced stage of decomposition. From this mineral the elements calcium, sodium and potassium are liberated in the form of soluble salts. Iron, manganese, phosphorous and other elements needed for plant growth are also liberated in form of soluble salts as a result of the decomposition of hornblende, apatite, and other minerals present. Because the smaller the grain the larger its surface in relation to bulk, the fine-grained minerals in loess yield their elements to water solution, and through it to plant roots, in proportionally greater amount than when the same minerals occur in coarser grains, as in sands or gravels. In surficial portions of loess the soluble minerals are being gradually removed, in part being taken by roots of plants, and in part being carried away by circulating water. The remaining salts are rendered less accessible for further solution because the alumosilicates, which are not soluble, tend to cover the surfaces of loess grains and also clog the passage ways between them. Thus loess deteriorates and gradually loses its original fertility and friability which is so valuable for crop production. On the other hand, as engineers find, the loess which has lost part of its

original porosity and reached greater compactness becomes better material for roads and other engineering structures.

There seems to be no doubt that it is loess with its fine-grained, friable structure, and with its fertility, that is the main factor in making our land most suitable for many crops. Hence it is the source of our agricultural richness. They often call petroleum "black gold" for the wealth which it brings to the nation. The humble "yellow dirt," as loess is called by farmers, which by its productivity is fundamental to our existence could be called with still greater propriety the *golden earth* of agriculture.

World distribution of loess and loess-like deposits, in large part closely associated with glacial drift deposits, coincide with the large wheat-producing areas of the world The wheat and corn belts of the United States are coextensive with the areas underlain by loess and the "highly calcareous glacial accumulations." Wheat is grown on the soils developed from loess in Kansas, the leading wheat producing state, and in the other loess states, such as Nebraska, Illinois and Missouri; the corn of the leading corn producing state of Iowa grows on soils developed from loess. Marbut's (1930) "highly calcareous drift" zone covers the rest of the leading wheat and corn producing states: Montana, North and South Dakota, Minnesota, Indiana and Ohio. The isolated highly productive wheat region of Washington, Oregon and Idaho is coextensive with the loess deposits of the Columbia Plateau, and the extreme southwestern extension of the "hard winter wheat region" of the Mid-West in Oklahoma, Texas and New Mexico is located on patches of loess in the High Plains region (not shown on Marbut's generalized map).

A similar correlation of principal wheat producing areas and loess distribution holds true the world over. In Russia the wheat of the Ukraine and lower Volga River region is on the chernozem-capped loess (see Obruchev's account of loess distribution in this symposium). The bread-basket of the ancient world, the wheat-producing central-Asiatic possessions of Russia, has much loess-derived soil. Here the virgin loess of the foothills of the huge mountain-chains is, in some places, purposely washed by man down into the valleys to produce an artificial veneer of "soil" for better crop production. The wheat of Argentina comes from the great region of loess distribution in South America (Hobbs, 1943, fig. 16, on p. 298), and the

wheat of North Africa is grown on loess-covered regions. Only China's great masses of loess deposits are not used for wheat production, but rice and other staple oriental grains are raised there.

In contrast with soil developed from the inexhaustible amount of golden earth of the northern Mid-West, the soils, which have but little loess material and were formed under the forest belt east of the Great Plains, are frequently thin and irreplaceable. While these soils produced wonderful crops for the pioneer farmer, who cleared the forest and tilled the land thus made available, they did not continue to produce in abundance and were nearly exhausted within a few generations, becoming poor land unable to support the living progeny of the once prosperous pioneers.

Some economists in the east, who were alarmed by the dust storms of the middle west, suggested abandonment of tillage in western prairies and the turning of most land to moderate grazing. While reasonable precautions to safeguard against erosion and blowouts are essential for conservation and proper utilization of the land, general condemnation of dry farming in these areas is unreasonable. Instead, as the experience of our tenacious and progressive farmers show, dry farming combined with irrigation from rivers and creeks, and from shallow and deeper wells, assures continuous production of valuable crops in the drier parts of the Mid-West. Large scale wheat raising produces and will produce most of our bread. Compared with other parts of our country it is the northern part of the Mid-West, where the inexhaustible golden earth is located and where it is possible to maintain production of wheat, corn, potatoes and other fundamental foods for many generations to come, safeguarding a normal supply of these essentials of life for our own nation, as well as an emergency surplus for the rest of the world.

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Marbut, C F 1936. Map of "Distribution of parent materials of soils" (1931), opposite p. 17, Atlas of American Agriculture, part 3, Soils of the United States, by C. F Marbut. Published by the U. S Department of Agriculture, Washington, D. C.

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PLEISTOCENE[1] LOESS DEPOSITS OF NEBRASKA.

C. BERTRAND SCHULTZ AND THOMPSON M. STOUT.

ABSTRACT Four important loesses are recognized in the Pleistocene of Nebraska The stratigraphy of the Pleistocene sediments is reviewed with emphasis on the placement of loess deposits in relation to marl and peat beds, buried soils, and terrace sequences. A climatic interpretation is based upon a terrace cycle concept in which loess is regarded as a product of drought and soil a result of relatively humid conditions.

The Broadwater formation is described as early Pleistocene in age and consisting of three parts, a basal and upper gravel deposit separated by finer textural sediments (the Lisco member) A loess-like silt appears in the Lisco member. A very late Pleistocene loess, the Bignell formation, is named

INTRODUCTION.

THE four principal loess deposits in the Pleistocene of Nebraska and adjacent states are listed, in order of deposition, as follows·

(1) Medial Pleistocene yellowish gray loess (perhaps part of the Upland formation); fossiliferous and well exposed near Angus, in Nuckolls County, Nebraska. This is also recognized in the Hay Springs-Rushville-Gordon collecting area, Sheridan County, Nebraska

(2) Medial Pleistocene reddish buff loess (the Loveland formation); recognized throughout Nebraska and adjacent states; traceable from the type locality at Loveland, Iowa. The thick soil of the *Citellus* Zone is developed on top of the Loveland loess. A valley phase of the Loveland is rather well known.

(3) Late Pleistocene yellowish gray loess (the "Peorian" formation); recognized throughout Nebraska and states to the east; traceable from the Illinois type area to western Nebraska. The thick *Citellus* Zone soil occurs at its base, grading upward into the "Peorian" loess. A valley phase of the Peorian, which is usually unconformable on the Loveland, is also known. The erosional interval seems to have occurred principally after the main part of the *Citellus* Zone soil had been developed.

(4) Very late Pleistocene gray loess (the Bignell formation, new); well exposed near Bignell, Lincoln County, Nebraska, where it is separated from the "Peorian" loess by a well-defined soil.

Early Pleistocene loess-like silts (part of the Lisco member of the Broadwater formation, both new) are well developed

[1] All deposits which are post-Ogallala in age are considered as Pleistocene in this paper

along the north side of the North Platte River in Garden and Morrill counties, Nebraska.

Each of the five deposits mentioned above seems to represent an important event in the Pleistocene history of the Great Plains, and each apparently has had a similar position within the Pleistocene sedimentary cycles of this region. The discussion which follows will briefly relate the loess deposits to the more general stratigraphic and faunal record, after which a broad interpretation of the loess in relation to soils, cutting-cycles, and climate will be attempted.

Emphasis is placed upon the terrace and terrace-fill sequences on the North Platte, South Platte, Platte, Niobrara, White, and Republican rivers. The terraces are not necessarily equivalent in all drainages, but nevertheless seem to be regional in their development. They are numbered in order from the water level upward, with the normal flood-plain designated as T^0, the first terrace as T^1, etc. This nomenclature implies the correlation of terraces between the various river valleys and their tributaries in the western Nebraska area. Regional climatic and possibly tectonic controls known to have been operating throughout the Cenozoic history of the Great Plains, appear to have been contributing factors to this widespread terrace development.

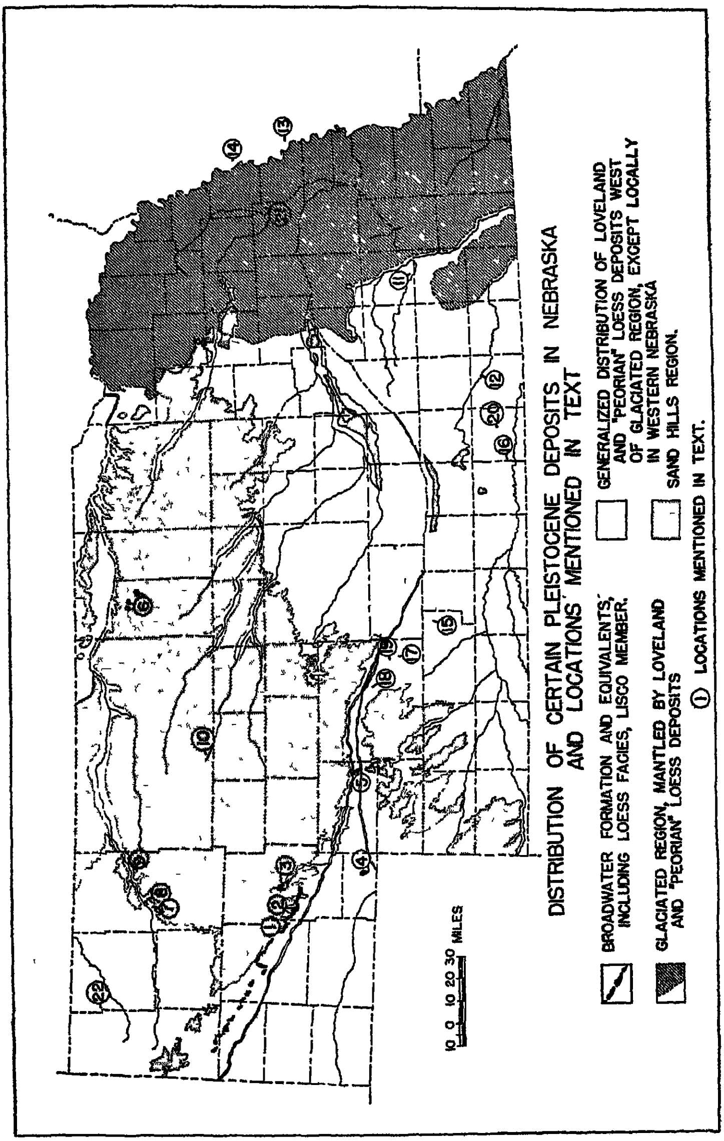
LOWER PLEISTOCENE DEPOSITS.

The oldest known Pleistocene deposits in Nebraska do not contain a true loess, but a loess-like silt does occur in western Nebraska along the north side of the North Platte River, from near Lisco in Garden County to near Bayard in Morrill County. This loess-like silt is a part of the Lisco member of the Broadwater formation (both new).

The term "Broadwater formation" is proposed here for sediments of early Pleistocene age, particularly well exposed in the vicinity of Broadwater and Lisco, in Morrill and Garden counties, Nebraska, where it has been intensively studied. These sediments have yielded the largest known collection of early Pleistocene mammalian remains[2] yet discovered on this continent. The type locality of the Broadwater formation,

[2] Barbour, Erwin H, and Schultz, C. Bertrand: 1937, An early Pleistocene fauna from Nebraska; Amer. Mus. Novitates, No 942, pp 1-10.
Schultz, C. Bertrand, and Stout, Thompson M.: 1941, Guide for a field conference on the Tertiary and Pleistocene of Nebraska; Special Publ., Uni. Nebr. State Museum, pp 13, 27, Figs 3-4, Table 3.

and of the Lisco member, is at the Broadwater Locality A of the University of Nebraska State Museum (Locality 1, Text Fig. 1), where the most important fossil quarries occur, in



Text Fig. 1. Map of Nebraska showing localities mentioned in the text, except for Locality 21 which is the Fremont section, representative for the glaciated region (*see* Lugn, 1935).

secs. 20 and 21, T. 19 N., R. 47 W., Morrill County, Nebraska. Here the stratigraphy is relatively simple (Text Fig. 2). The Ogallala sediments were rather deeply eroded, probably by an ancestral North Platte River, and then the alluvial deposits, which constitute the Broadwater formation, were deposited in the following order (Text Fig. 2):

(1) Basal gravel member, composed of reddish brown "crystalline" gravels.

(2) Lisco member, defined as including all sediments between the basal and upper gravel members, but consisting here of diatomaceous marl and peat, with sand and silt lenses.

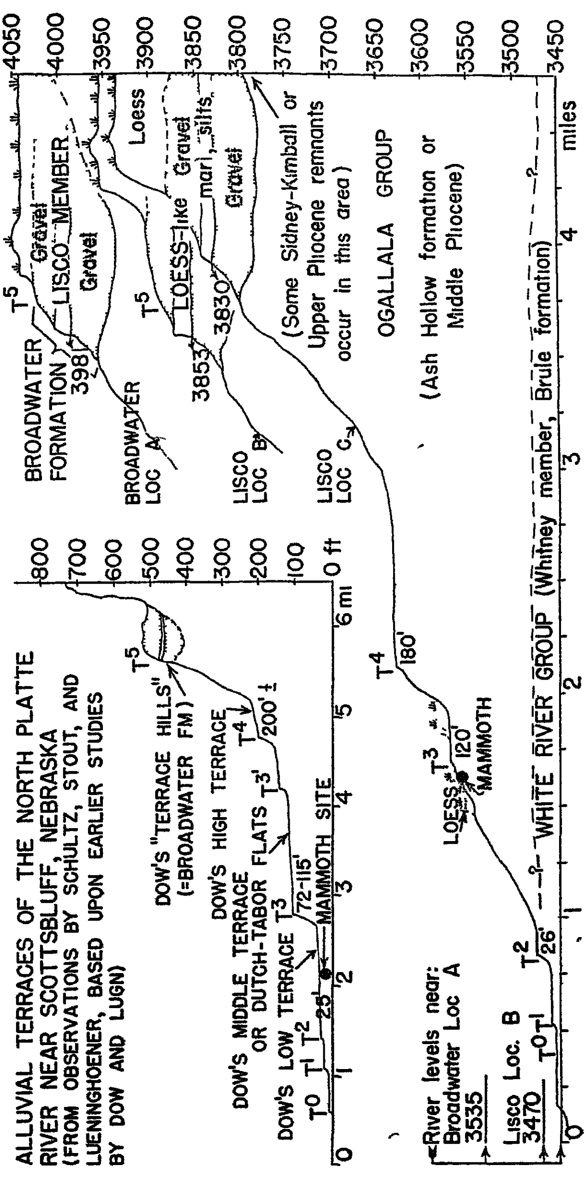
(3) Upper gravel member, similar in every way to the basal gravel member

A section measured at the type locality of the Broadwater formation, at Broadwater Locality A, Quarry 1, in NE. ¼, sec. 20, T. 19 N., R. 47 W, Morrill County, Nebraska is given below:

Broadwater formation	Feet
7. Upper gravel member	10–15±
6 Sand, fine buff gray	2 5
5. Silt and fine sand, light gray	1 5
4. Diatomaceous marl, relatively pure to impure, with sand lenses, fossils	0 6–1 5
3. Peat, chocolate-brown, impure; main bone layer	0 4
2. Sand, fine greenish gray, with occasional pebbles	3 0
1. Basal gravel member	45±

Beds 3 and 4 have produced most of the splendid collection of Pleistocene fossils from the Broadwater Locality A. The mammals include *Stegomastodon* (mastodont); *Camelops* (camel); *Tanupolama* (llama); *Platygonus* (peccary); *Plesippus* (primitive Blanco-type horse); *Nannipus* (holdover Pliocene horse); *Mylodon* (sloth); *Geomys* (gopher); *Procastoroides* (ancestral giant beaver); *Smilodon* (saber-tooth tiger); *Borophagus* (holdover Pliocene wolf); *Canis* (coyote); *Satherium* (otter); and others. Abundant frog remains supplement the evidence from the mammals and lithology to demonstrate the stream-side nature of the deposit.

To the east, at Lisco Locality A (Locality 2, Text Fig. 1), a loess-like silt facies is exceedingly well developed as a part of the Lisco member. The loess-like silt at this locality (Pl. 1, Fig. 1) is roughly contemporaneous with the diatomaceous marl and peat, beds 3 and 4 of the Broadwater Locality A, since



Text Fig 2 Terrace sequences along the North Platte River near Scottsbluff, Broadwater, and Lisco, Nebraska. T^0, T^1, T^2, T^3, T^4, and T^5 are successive terraces in order of vertical distance from present river (water) level. The figures at the right of the Broadwater-Lisco terraces designate the number of feet above sea level, while those at the right of the Scottsbluff terraces are above North Platte River (water) level

both facies are situated between the two gravel members. Alluvial and colluvial silts and sands also are locally contained within the Lisco member, as at Lisco Locality C.

A few of the same mammals found at Broadwater Locality A are encountered in the quarry sites in the loess-like silt and other deposits at Lisco Localities A, B, and C, but the most common and characteristic form is the giant camel, *Gigantocamelus fricki* Barbour and Schultz.[3] Only a few scraps suggest the presence of this giant camelid in the Broadwater Locality A. The other mammals found in the Lisco loess and associated sediments suggest an upland habitat, in contrast to the streamside habitat sampled in the Broadwater quarry sites.

The Broadwater formation is traceable in almost continuous outcrop as far east as the headwaters of Blue Creek (Locality 3, Text Fig. 1) in Garden County, Nebraska. The Lisco member throughout its area of known outcrop has a definite physiographic development, which is a prominent vegetation line predominated by Yucca. This is produced by ground water working down through the pervious upper gravel member until it reaches the compact fine textured Lisco member sediments, thus producing a moist, soft zone favorable for plant growth.

To the west, the Broadwater formation has been found to be the same (Text Fig. 2) as the Terrace Hills of C. L. Dow.[4] The loess-like silts have been recognized east of Northport and southwest of Angora in Morrill County.

Probable equivalents of the Broadwater formation have been recognized by the writers in the following localities: (1) in the divide between the North Platte and South Platte rivers, exposed in the Paxton Cut, north of Paxton, Keith County, Nebraska (Locality 5, Text Fig. 1); (2) in the South Platte River drainage, on the east side of Walrath Draw[5] east of Chappell, Deuel County, Nebraska (Locality 4, Text Fig. 1); and (3) in the Niobrara River drainage north (Sand Draw[6])

[3] Barbour, Erwin H., and Schultz, C. Bertrand: 1939, A new giant camel, *Gigantocamelus fricki*, gen. et sp. nov.; Bull. Uni. Nebr. State Museum, 2, No. 2, pp. 17-27.

[4] Lugn, A. L.: 1935, The Pleistocene geology of Nebraska; Nebr. Geol. Survey, Bull. 10, 2nd Series, pp. 168-172.

[5] A loess-like silt with concretions, correlated as the Lisco member, is exposed here between a basal and upper gravel sheet. Similar concretions also are exposed at the type locality of the Lisco member.

[6] McGrew, Paul O.: 1944. An early Pleistocene (Blancan) fauna from Nebraska; Field Museum Nat. Hist., Geol. Series, 9, No. 2, pp. 33-66.

and northeast (*Stegomastodon* Quarry of Osborn[7]) of Ainsworth, Brown County, Nebraska (Locality 6, Text Fig. 1).

MIDDLE PLEISTOCENE DEPOSITS.

A very rich collection of fossil mammals[8] has been accumulated over a period of years by the University of Nebraska State Museum and other institutions from the middle Pleistocene deposits south of Hay Springs (Locality 7, Text Fig. 1), Rushville (Locality 8, Text Fig. 1), Gordon (Locality 9, Text Fig. 1), and Mullen (Locality 10, Text Fig. 1), in Sheridan and Cherry counties, Nebraska.

The chief fossiliferous beds of the Sheridan County deposits consist of fine sand and some gravel, situated both below and above a prominent, fossiliferous, diatomaceous marl and peat bed, overlain by volcanic ash and Loveland and later loesses. These sediments comprise the fill and mantle of the 250-300 foot or high terrace (T^4) of the Niobrara River. Lugn[9] refers the pre-Loveland sediments of the fill to the Upland formation.

In eastern Nebraska there are several localities in which there are sediments probably equivalent to those of the Hay Springs-Rushville-Gordon quarry deposits. One is southwest of Milford, Seward County, Nebraska (Locality 11, Text Fig. 1), where the type specimen of *Mastodon moodiei* Barbour[10] was collected. At this site the fossiliferous zone is overlain in succession by diatomaceous marl and peat, sand, volcanic ash, and Loveland loess. Southwest of Angus in the SW. ¼ of the NE. ¼, sec. 33, T. 4 N., R. 6 W., Nuckolls County, Nebraska, there is an important fossiliferous middle Pleistocene loess which may be a part of the Upland formation described by A. L. Lugn.[11] The loess has a well developed soil upon it and must be considered as pre-Loveland since there is typical Loveland loess above the soil (Locality 12, Text Fig. 1).

The middle Pleistocene volcanic ash deposits of the Great Plains seem to be of extreme importance in correlation. These

[7] Osborn, Henry Fairfield: 1936, Proboscidea, Vol. I; American Museum Press, pp. 726-728.

[8] Schultz, C. Bertrand, and Stout, Thompson M.: 1941, op. cit.; pp. 38-44, Fig. 14, Table 4 (faunal lists).

[9] Lugn, A. L · 1935, op. cit.; p. 127.

[10] Barbour, Erwin H.: 1931, The Milford mastodon, *Mastodon moodiei*, sp. nov ; Bull Nebr. State Museum, 1, No. 24, pp. 203-210.

[11] Lugn, A. L.: 1935, op. cit ; pp. 119-127.

are widely distributed in southern, central, and eastern Nebraska,[12] and in northern Kansas. The ash has been studied by the writers in western Iowa only a short distance north of the Loveland type section (Locality 13, Text Fig. 1) in several gravel pits which constitute the "County-line exposures" of Iowa geologists, near Little Sioux, in the NE. 1/4, sec. 5, T. 81 N., R. 47 W., Harrison County, Iowa (Locality 14, Text Fig. 1). In these gravel pits, cross-bedded sands and gravels occur below the volcanic ash, with a sandy to loess-like silt situated between the sand and the ash.[13] The Loveland loess lies above the volcanic ash, but the sands and gravels, associated silts, and ash are included also in the Loveland formation by the Iowa geologists.[14]

The Pleistocene volcanic ash has a maximum thickness of about 50 feet[15] near Eustis, in Frontier County, Nebraska (Locality 15, Text Fig 1), where it is overlain by Loveland loess, the *Citellus* Zone soil, and "Peorian" loess (Pl. 1, Fig. 3). Lugn[16] places this ash and associated sands and gravels in his "valley phase" of the Loveland formation, while a green clay and related beds below the ash near Orleans, Nebraska, are placed in the Upland formation.[17]

An outcrop of volcanic ash 3.2 miles west and 2.4 miles north of Inavale, in the NE. 1/4 of the SE. 1/4, sec. 19, T. 2 N., R. 12 W., Webster County, Nebraska (Locality 16, Text Fig. 1), furnishes important information with regard to the relation between the ash and gravel deposits of the Republican River region. The volcanic ash bed overlies sand and gravel, which throughout this region has been termed Grand Island formation by Lugn,[18] and the ash is overlain by nearly 15 feet of sand and gravel, capped by Loveland loess. The upper gravels have been confused previously with the gravels below the ash. It is probable that many of the gravels formerly considered as Grand Island are in reality Loveland gravels, and the basal gravels may belong in part to the Upland formation.

Another important locality is south of Brady, in the SW.

[12] Lugn, A. L.: 1935, op. cit.; pp 132-134

[13] Kay, George F, and Graham, Jack B.: 1944, The Illinoian and post-Illinoian Pleistocene Geology of Iowa; Iowa Geol. Survey, Special Report, Pt. 2, pp 85-88.

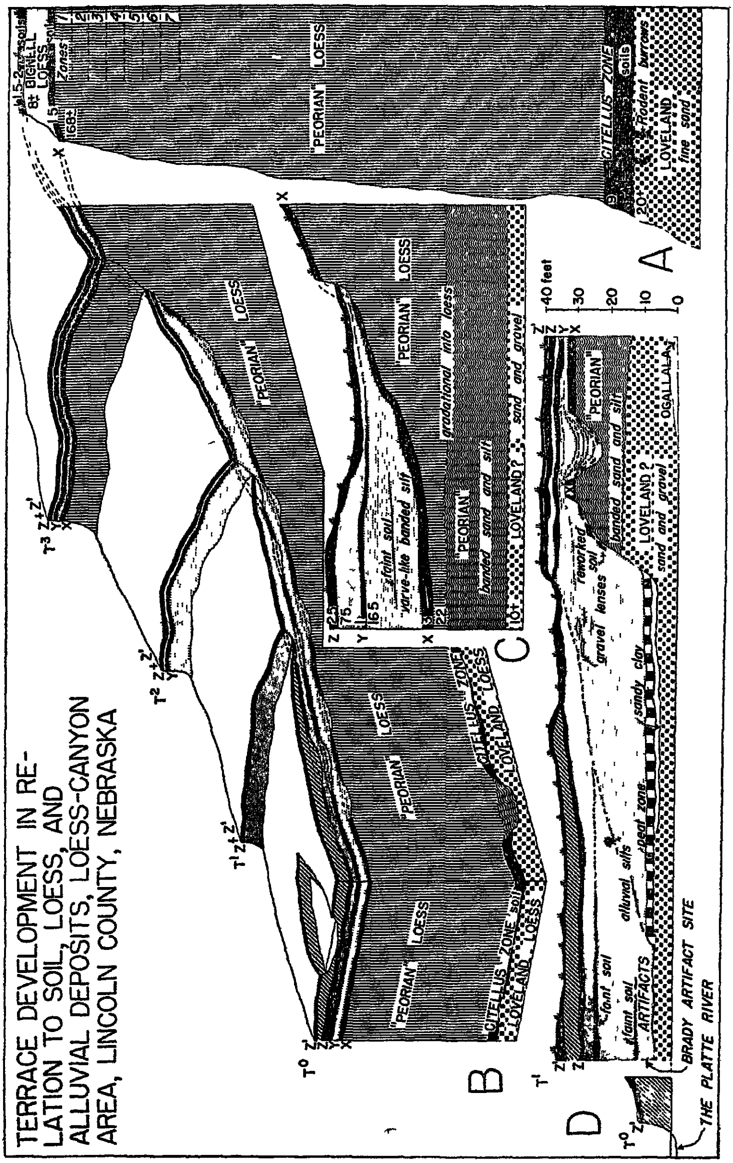
[14] Kay, George F, and Graham, Jack B.: 1944, op cit; p. 85.

[15] Lugn, A. L.: 1935, op. cit., p 132.

[16] Lugn, A. L.: 1935, op. cit; pp 128-134.

[17] Lugn, A. L: 1935, op. cit; pp. 119-127, 134-135.

[18] Lugn, A. L.: 1935, op cit.; pp. 103-119.



Text Fig. 3. Terrace development in the loess-canyon area on the south side of the Platte River, south of Brady, Lincoln County, Nebraska. X, Y, Z, and Z′ are successive late Pleistocene-Recent soils in the order of development as indicated. T^0, T^1, T^2, and T^3 are successive terraces in the order of vertical distance from the present river (water) level Zones 1, 2, 3, etc, near the top of profile A, indicate collecting levels where invertebrate fossils were obtained.

¼, sec. 1, T. 10 N., R. 27 W., Lincoln County, Nebraska (Locality 17, Text Fig. 1), where a lens of volcanic ash, which measures up to 11 feet thick, is underlain by 11 feet of red Loveland loess and overlain by 35 feet of the same type of loess. Above this are four feet of *Citellus* Zone soil and 93 feet of "Peorian" and later loess. This outcrop shows that Loveland loess may occur below volcanic ash as well as above it. Even at the Eustis site, mentioned previously, the volcanic ash seems to interfinger in part into the Loveland loess.

Much additional study will be necessary to solve some of the complex problems with regard to correlation and nomenclature of these middle Pleistocene deposits.

UPPER PLEISTOCENE DEPOSITS.

The study of the late Pleistocene of the Great Plains involves an analysis of the loess, soil, and alluvial deposits in relation to the terraces. As mentioned previously, the late Pleistocene and Recent terraces (T^3, T^2, T^1, T^0) appear to be easily and rather definitely correlated from one drainage to another throughout Nebraska, southwestern South Dakota, western Wyoming, and probably the remainder of the Great Plains. The fossil mammals have been tied into the terrace sequence, and substantiate the correlations based upon other criteria.

An important area containing upper Pleistocene deposits is the great loess area south of the Platte River, southeast of North Platte, in Lincoln County, Nebraska (see Text Figs. 3, 4; Pl. 2, Fig. 2). Text Fig. 3A illustrates the section at Bignell Hill (Locality 18, Text Fig. 1), where Loveland fine sand is overlain by the *Citellus* Zone soil, very thick "Peorian" loess, soil X, an upper loess, and a complex top soil. This is a representative section for the entire loess-canyon area. The *Citellus* Zone, which includes not only the soils at the top of the Loveland but also the transitional few feet of the

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EXPLANATION OF PLATE 1

Fig. 1. Loess-like silts (Lisco member of Broadwater formation) at Lisco Locality A, northeast of Lisco, Garden County, Nebraska (Locality 2 on map, Text Fig. 1).

Fig. 2 Fossil quarries in middle Pleistocene deposits, south of Rushville, Sheridan County, Nebraska (Locality 8 on map, Text Fig. 1).

Fig 3. *Citellus* Zone soil (S) with yellowish gray "Peorian" loess above and reddish buff Loveland loess below. The soil is approximately five feet thick in this area southwest of Eustis, Frontier County, Nebraska (Locality 15 on map, Text Fig. 1). Volcanic ash is exposed below the Loveland loess and is visible at the base of the picture.

FIG. 1.

FIG 2.

FIG 3.

FIG. 1.
Citellus Zone soil (S) with "Peorian" loess above and Loveland loess below, northeast of Cowles, Webster County, Nebraska (Locality 20 on map, Text Fig 1). A layer of gravel is exposed at the base of the bluff below the Loveland loess.

FIG. 2.
Terraces developed in loess-canyon area southwest of Brady, Lincoln County, Nebraska (Locality 19 on map, Text Fig 1).

FIG 3
Terraces developed along White River drainage south of Interior, Washabaugh County, South Dakota Loess is exposed at the left of the picture in a "high" terrace which is definitely below the summit pediment surface (T^5 or earlier) of the Big Badlands.

"Peorian" loess, is quite fossiliferous. Observations by the writers in 1934, and confirmed in *later* seasons of work here, demonstrate that most of the fossil mammal remains from this area are derived from this faunal zone.[19] The most spectacular form represented is the mammoth *Archidiskodon maibeni* Barbour, a mounted skeleton of which is on display in the University of Nebraska State Museum. The *Citellus* Zone soil is very widely distributed and can be traced from western Iowa through most of Nebraska to northern Kansas, eastern Colorado, and Wyoming.[20] It is fossiliferous throughout much of the area.

The Bignell Hill section (Text Fig. 3A) has been selected as the type section for the Bignell formation (new), because the upper loess here is definitely separated from the "Peorian" loess by a prominent soil (soil X of Text Fig. 3A) and overlain by a complex top soil. The type locality is 1.7 miles due south of Bignell, southeast of North Platte, in the E. ½ of the E. ½, sec. 3, T. 12 N., R. 29 W., Lincoln County, Nebraska. The writers believe that the recognition of this late Pleistocene loess will simplify later studies of the terrace soil, and loess deposits of the Great Plains. As suggested in Text Fig. 3, there appear to be extensive alluvial deposits in the loess-canyon area of Lincoln County, Nebraska, which also are contained within the Bignell formation.

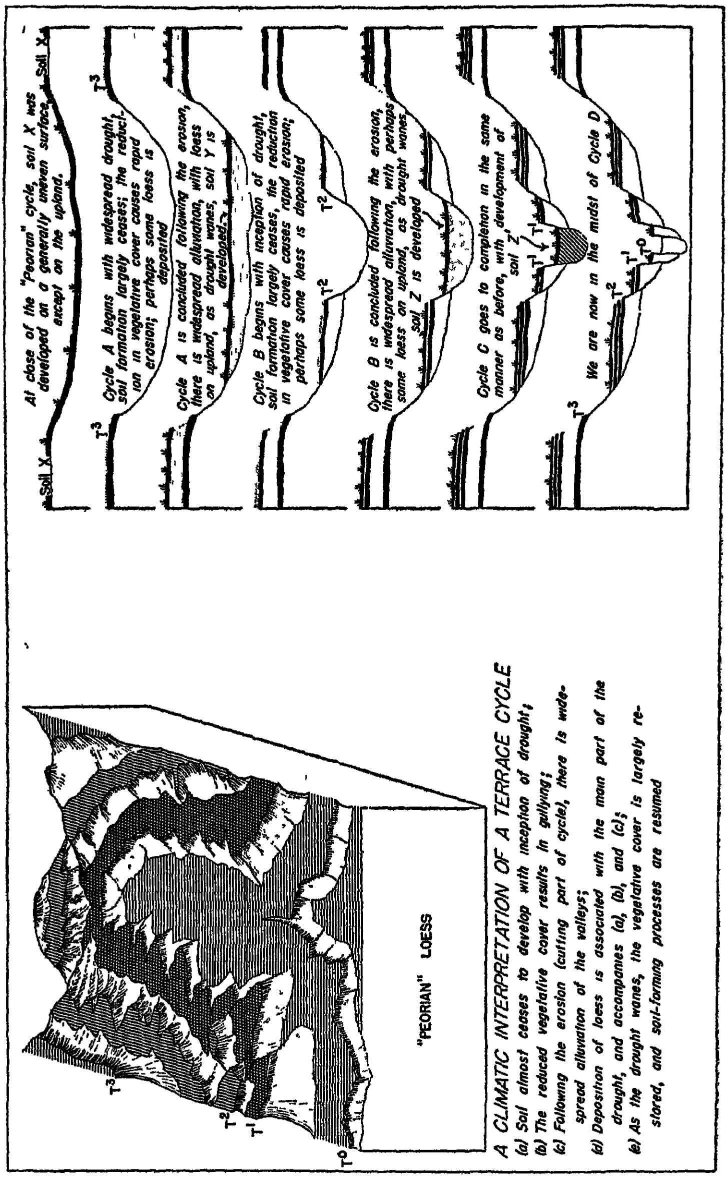
Text Fig. 3B is a schematic (not to scale) representation of the terraces in relation to soils and related deposits in the loess-canyon area, restored as though each period of cutting removed only part of the preceding fill and soil deposit. Another method of representation is used in Text Fig. 4.

Text Fig. 3C is a section (scale as indicated in Text Fig. 3D) at the Jeffrey Canyon Power House excavation, south of Brady, Nebraska (Locality 19, Text Fig. 1) showing transitional upland-valley sediments.

Text Fig. 3D is a section (scale as indicated) from the bridge across the Jeffrey Canyon Canal south of Brady along the canal excavation for 1483 yds. toward the locality illustrated

[19] Schultz, C. Bertrand· 1934, The Geology and Mammalian Fauna of the Pleistocene of Nebraska; Bull. Nebr State Museum, 1, No 41, Pt 2, pp. 359-360.

[20] The writers are preparing a report for publication in 1945 on the fauna of the *Citellus* Zone The stratigraphic work and correlation of this zone have been done in cooperation with the Nebraska Geological Survey. A name will be applied to the *Citellus* Zone soil.



Text Fig. 4. The sequence of events of terrace development in the loess-canyon area in Lincoln County, Nebraska, and the concept of a Terrace Cycle. See Text Fig 3.

in Text Fig. 3C. This is an interpretation of the exposed section through the first terrace above the flood-plain (T^1) of the Platte River.

The terraces recognized in the Lincoln County loess-canyon area are correlated tentatively with the terraces up the North Platte River from Lisco to Scottsbluff (see Text Fig. 2). The

Suggested Correlations of Pleistocene Sedimentation Cycles in Nebraska and Adjacent Areas.

	Standard[22]		Supposed Cycles in relation to Terraces		Faunas
Wisconsin	Present events	Post-"Peorian"	Cycle D or present cycle ——T^0 = flood plain—— Soil Z′ Cycle C	"Recent" Faunas	Present-day fauna
	W4 = Cochrane		——T^1 (= Kuner?)[22]—— Soil Z Cycle B		Faunas associated with buried hearth sites in T^1
	W3 = Mankato		——T^2 (= Kersey?)—— Soil Y Cycle A (Bignell loess)		EXTINCTION VERY LATE PLEISTOCENE (faunas associated with Yuma-Folsom complex)
	Two Creeks Forest Bed W2 = Tazewell-Cary		——T^3 (= Pleasant Valley?) Soil X		
	"Peorian" W1 = Iowan		"Peorian" Cycle Complex		
	Sangamon Illinoian		——Erosion—— *Citellus* Zone Soil Loveland Cycle		LATE PLEISTOCENE (*Citellus* Zone fauna)
	Yarmouth Kansan		——T^4—— Soil Upland Cycle Complex		MEDIAL PLEISTOCENE (Hay Springs-Rushville-Gordon quarry sites, etc)
	Aftonian Nebraskan		——T^5—— Broadwater Cycle Complex (?)		EARLY PLEISTOCENE (Broadwater-Lisco quarries, etc.)[23]

[22] Wisconsin subdivision and terrace names within brackets are from Bryan, Kirk: 1941, Correlation of the deposits of Sandia Cave, New Mexico, with glacial chronology; Smithsonian Misc. Collections, 99, No. 23, pp 45-64 Also Bryan, Kirk and Ray, Louis L: 1940, Geologic antiquity of the Lindenmeier Site in Colorado; Smithsonian Misc. Collections, 99, No. 2, pp. 36-69.

[23] The exact age of the sediments in the Broadwater-Lisco quarries is in question. They may be as old as early Nebraskan or as late as Aftonian. The Blanco deposits of Texas appear to be equivalent, at least in large part

Scottsbluff Bison Quarry[21] without question occurs within the T^2 terrace, in sediments correlated with the Bignell formation. Mammoth remains found east of Scottsbluff (Text Fig. 2) also occur in this terrace.

In the drainages of the White and Cheyenne rivers in Sioux and Dawes counties, Nebraska, there are terraces which appear to correspond to the T^2, T^1, T^0 of the Platte River valley. The faunas of the T^2 terraces of both areas are the same, with *Bison antiquus taylori* occurring most frequently. Yuma and Folsom artifacts also occur in this terrace (Locality 22, Text Fig. 1). The late Pleistocene extinction of many of the important large mammals appears to have occurred during the time of the basal fill of T^2.

ACKNOWLEDGMENTS.

The present report is a summary based upon related studies, long continued, with regard to the stratigraphy and vertebrate paleontology of the Cenozoic deposits of the Great Plains. The writers are indebted to Dr. Erwin H. Barbour and Dr. Childs Frick for support of the projects. The assistance and coöperation of the following colleagues are appreciated: Mr. E. L. Blue, Dr. Kirk Bryan, Dr. M. K. Elias, Dr. Jack Graham, Capt. Joe Johnson, Lt. A. L. Lugn, Dr. Paul MacClintock, and Prof. E. C. Reed. Prof. Gilbert Lueninghoener has provided much aid and helpful suggestions concerning terrace correlations. Messrs. W. F. Chaloupka, Charles H. Falkenbach, Russell Langford, T. C. Middleswart, Morris F. Skinner, and S R. Sweet have been very kind in supplying information concerning Pleistocene fossil localities. The Text Figures were drafted by Thompson M. Stout and the photographs for the Plates were taken by C. Bertrand Schultz.

[21] Schultz, C Bertrand, and Eiseley, Loren: 1935, Paleontological evidence for the antiquity of the Scottsbluff Bison Quarry and its associated artifacts; Amer. Anthropologist, 37, No. 2, pp. 306-319.

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GLACIAL VERSUS DESERT ORIGIN OF LOESS.

KIRK BRYAN.

ABSTRACT The main source of loess is the outwash of glacial rivers pulverized by frost action. The main areas of its deposition were marginal to the region most affected by the glacial born anticyclonic winds combined with prevailing westerlies Steppe loess has its source in the adjacent deserts. The structural similarities in loesses of different origin are due to secondary processes induced by grass vegetation.

Flood plains of Nebraska rivers, which in Pleistocene time were overloaded, glacial-fed streams, were the source of the loess in the State

THE formation and deposition of wind-borne and wind-deposited silt (loess) is a complex process requiring (1) source of silt; (2) adequate winds blowing predominantly or in net effect from one direction; (3) an adequate place for deposition. This relatively simple chain of thought leads to the conclusion that the flood-ravished outwash plains of glacial rivers made pulverent by frost action form ideal sources of silt. To a lesser extent recently uncovered till plains kept free of vegetation by frost action are also sources. The outblowing or anticyclonic winds of glacial ice masses are combined with the prevailing westerlies to form a system of favorable winds. Places of deposition occur in the tundra-forest border which in middle latitudes once surrounded the Pleistocene ice sheets. Excessive frost-action in these areas was, however, a factor in the removal of wind-borne silt as fast as it was deposited. Large bodies of loess are therefore largely preserved in areas somewhat more marginal to the region most affected by the anticyclonic winds.

The secondary changes in the wind-borne silt give the material its buff color, vertical structure, and in part its calcareous content. These characteristics are induced by the edaphic effect of grass cover which tends to develop on silt in a zone which is generally forested. Loess of glacial origin thus resembles in its secondary features the loess of the steppe zones surrounding desert areas. However, production of dust in deserts is inhibited by the formation of the desert pavement and also by the lack of wind. Only the great trade-wind deserts have strong winds blowing consistently or dominantly in one direction. Thus the Sahara produces dust which is deposited

to the South in the Sudan and also on the west in the "Dark Sea" off the shores of Mauretania. Some deserts like that of Chile are, because of calm air, depositories of dust.

In Nebraska the relative influence of glacial and desert sources is acute. It should, however, be borne in mind that the Platte and Missouri Rivers and all their Rocky Mountain tributaries, were in Pleistocene time overloaded, glacially-fed streams. To the extent that their flood plains are the source of Nebraska loess, this loess is essentially a glacial rather than a desert loess.

DISCUSSION.

Between James Thorp and Kirk Bryan.

THORP: 1. Bryan suggests that loess probably has accumulated most abundantly in periglacial areas. I wonder if we could lay a little more stress on the importance of glacial alluvial outwash as a source of the dust, this being, of course, a periglacial phenomenon. In many places the alluvial outwash plains are obviously a source of much of this dust we see accumulated. For example, in Colorado and Wyoming there are islands of loess which occur in association with old outwash plains and alluvial fans. On one of the older of these alluvial-fan remnants in Star Valley, Wyoming, and on adjacent areas of upland which have not been eroded since the time of loess deposition, we find loess deposits and we do not find them on the lower levels. We also find similar islands near Jackson, Wyoming, and assume that outwash from the glacier of that particular area was the source of the loess. The loess is not continuous with the larger deposits farther west.

2. Great loess accumulations southeast of the Ordos Desert in China suggest the desert to be a source of the loess. In that vicinity there is no large alluvial plain that could be interpreted to be the source. In the neighborhood of Loyang in northern Honan Province, I measured a meter thickness of loess over roof tiles, bricks, and other evidences of human culture which could not have been older than about 2000 years. This loess deposit is still accumulating and the dusts of which it is made are blown up from adjacent river valleys (the Loho and Yellow River). Thick clouds of dust can be seen on almost any day from autumn until late spring, borne southeastward by the prevalent northwest winds of the winter

phase of the monsoon. In the Yangtze Valley in the neighborhood of Nanking, there are thick deposits of clayey material of a slightly reddish or light-brown tint which appear to be aeolian in origin. These deposits are closely associated with the flood plains (or former flood plains) of eastern China. Most of the material is now too strongly weathered to bear the name "loess." Deposits of this type near Nanking are known as "Siashu loams."

Another deposit of material, aeolian in origin but not loess in the true sense of the word, was seen in the Szechuan Basin in west China. It occurs on terrace remnants and on adjacent uplands eastward from the Chengtu Plain and elsewhere in the Tibetan borderland.

BRYAN: Regarding the importance of recent alluvium as a source of loess, two questions arise: 1. Whether ordinary alluvium in arid regions, which has no connection with the glacier, forms a source of loess. In any of the generalizations, the exception is always possible and I have no doubt that there are places where dust is being accumulated at the present time. There are also volcanic dusts being accumulated, some of which are mixed with the dusts that are not actually blown out of a volcano but are picked up. This occurs in Mexico where the origin of this theory began. There are no doubt places in China where there is an accumulation of loessial material as of the present day which is not necessarily evidence of the origin of the older and thicker deposits. In many parts of the world, dust which we see is partly man-induced. There probably are exceptions but generally speaking the great bodies of loess, are of the past. Are they something which comes out of the desert associated with a dry climate or do they come out of a desert associated with a glacial deposit? In other words, is it not likely that loess deposits from deserts may owe their accumulation to periglacial phenomena?

THORP: Do you think that of the loess that accumulated during the ice age the greater part came from outwash plains or from till?

BRYAN: I would say that in Europe and in the eastern United States the greater part of the loess was obtained from the outwash but one cannot deny that a till plain might be a favorable place to gather dust. That is being studied at the present

time. Relationship of vegetation to frost action is an interesting point to study in this connection. In Alaska there is a contest between the intensity of frost action and the tundra. If we can determine how close to the continental ice sheet the tundra encroached, we will be able to answer your question. Pollen studies will be one means of determining this. They will reveal information regarding the status of vegetation upon the continental ice. A bare area was present and a large tundra area probably went as far south as Missouri and North Carolina.

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A MECHANICAL ANALYSIS OF WIND-BLOWN DUST COMPARED WITH ANALYSES OF LOESS.

ADA SWINEFORD AND JOHN C. FRYE.

ABSTRACT. A mechanical analysis has been made of wind-blown dust collected in September, 1939, from the level of the third floor of the Lakeway Hotel, Meade, Kansas Comparisons of this analysis with previously published analyses of loess and new analyses of Kansas loess seem to demonstrate that wind can be competent to sort material to the degree represented by some loess deposits.

INTRODUCTION.

RUSSELL (1944, pp. 1-40) recently described loess deposits along the lower Mississippi valley, discussed at some length their possible origin, and concluded that loess is probably of fluvial-colluvial origin. His ideas concerning the origin of loess differ from those held by some geologists. Russell's paper has served to emphasize the fact that the origin of loess is not a closed question, and that some deposits that have been called loess at different localities may have had different origins. The present paper is concerned with only one of the data used by Russell in arriving at his theory of the origin of loess, namely the degree of sorting of the material. He stated (p. 24) that in loess:

"The sorting appears to be too uniform to be the result of direct deposition from a current. It seems improbable that either wind or water could move with the uniform velocity required to permit the accumulation of material so homogeneous that at least a half and ordinarily about three-fourths of its particles (by weight) fall within the limited diameter range 0.01-0.05 mm."

During a dust storm of about two hours duration in September 1939, dust accumulated to an estimated depth of 1/16 inch on surfaces near open third floor windows in the Lakeway Hotel at Meade, Kansas. These windows are about 25 feet above street level. Frye collected a sample of this dust from enameled surfaces which had been cleaned earlier in the day, and stored the sample in a sealed container. The foregoing statement made by Russell prompted the writers to

TABLE I. Size distribution of wind-blown dust and Sanborn loess samples.

Sample Number	Location	Size distribution in mm. (per cent by weight). 2-1	1-.5	.5-.25	.25-.125	.125-.0625	.0625-.0312	.0312-.0156	.0156-.0078	.0078-.0039	.0039-.00195	.00195-.00098	<.00098
Dust	Meade, Kansas.	0.04	0.19	0.38	1.64	8.45	41.85	24.41	5.68	8.89	5.81	2.67	5.55
1	SE cor. sec. 23, T. 1 S., R. 42 W. Cheyenne County, 30 feet above base of exposure.			0.06	0.80	4.72	60.32	20.55	5.43	2.01	1.30	0.83	4.49
2	SW cor. sec. 4, T. 1 S., R. 41 W Cheyenne County, road cut.				0 06	3.42	67.25	16 75	3.99	1.82	1.14	0 80	4.78
3	SW sec. 28, T. 3 S., R. 36 W. Rawlins County, 25 feet above base of loess.			0 04	0.07	3 30	55 88	22.40	6.95	2.98	1 70	1 13	5 53
4	NE NE sec. 18, T. 8 S., R. 36 W Thomas County, in road cut.				0.37	1.45	53.22	22.64	7.27	4.30	2.48	1 49	6.78
5	SW sec 31, T. 10 S., R. 36 W. Thomas County.		0 09	0 24	0 29	4 41	55.48	22.40	5.69	4 36	1 82	0 97	4.24
6	NE NE sec. 8, T. 8 S, R. 35 W. Thomas County, in railroad cut 7 feet below surface.			0 07	0.30	2.49	58 03	23 81	5.72	2 66	1.46	0.40	5.05
7	SW SE sec 32, T 10 S., R. 32 W. Thomas County, 10 feet below surface in road cut.				0.03	2.02	49 41	27.97	8 32	3 70	2.08	1.39	5 09
8	SW SE sec. 32, T. 10 S., R. 32 W. Thomas County, 5 feet below surface in road cut.			0 06	0.06	0 80	53 43	26 65	7 91	3 19	1 53	1.02	5.36
9	NW cor. sec. 30, T. 8 S., R. 31 W Sheridan County, 4 5 feet below surface in road cut.					0.94	46.01	28 33	9.59	4 80	2.40	1 80	6.14
10	NE sec. 6, T. 3 S, R. 27 W. Decatur County, base of loess.		0 12	0 33	0 33	1 51	37.36	29 81	13.28	6.04	3 62	1 81	5.79
11	NE sec 6, T. 3 S., R. 27 W. Decatur County, 5 feet above base of loess.					2 62	51.10	25 96	8.13	3.54	1.84	1 05	5.77
12	NE sec 6, T. 3 S, R. 27 W. Decatur County, 10 feet above				0 03	3 75	49 94	24 56	9 55	3.75	1 59	1 25	5 57

analyze this dust in an attempt to test the validity of his conclusion concerning the inability of wind to produce the degree of sorting observed in loess samples.

In order to compare the dust collected at Meade with High Plains loess deposits, size analyses were made of 12 samples of loess collected in 1943 from the Sanborn formation of northwestern Kansas. The location and analyses of these samples are given in Table I.

Udden (1914, pp. 720-726) published analyses of dust, and stated that most eolian deposits are better sorted than most water deposits. Direct comparisons with Udden's analyses have not been made because (1) his analytical methods were quite different from those used in the present study, and (2) the dust samples that he analyzed either were deposited after being transported only a very short distance by wind (such as dust stirred up by a running train and deposited inside the coach) or were collected from the atmosphere where it contained only a small concentration of dust. Thus his samples may not be comparable to the material transported and deposited by western Kansas "dust storms" such as transported and deposited the sample of dust herein described.

ANALYSES.

The dust and loess were prepared for analysis by digesting 30 to 40 grams of sample in hot hydrochloric acid. The acid was removed by six filterings through a Pasteur-Chamberland filter. Each sample was then dried, weighed, dispersed with sodium oxalate solution, and wet-sieved. The fraction caught on a 1/16 mm. sieve was dried, disaggregated with a rubber pestle, and sieved through screens of Wentworth grades. The silt collected in the pan was added to the sodium oxalate solution, and enough solution was added to make a liter. Six portions were withdrawn by a pipette to determine the per cent of material in each Wentworth grade from 1/32 to 1/1024 mm.

COMPARISONS OF SIZE DISTRIBUTIONS.

In order to compare the size distributions of the sample of wind-blown dust with the samples of Sanborn loess and with analyses of Mississippi valley loess published by Russell, plotted cumulative curves of the loess analyses have been superposed (Fig. 1) on the the curve of the dust analysis. The similarity

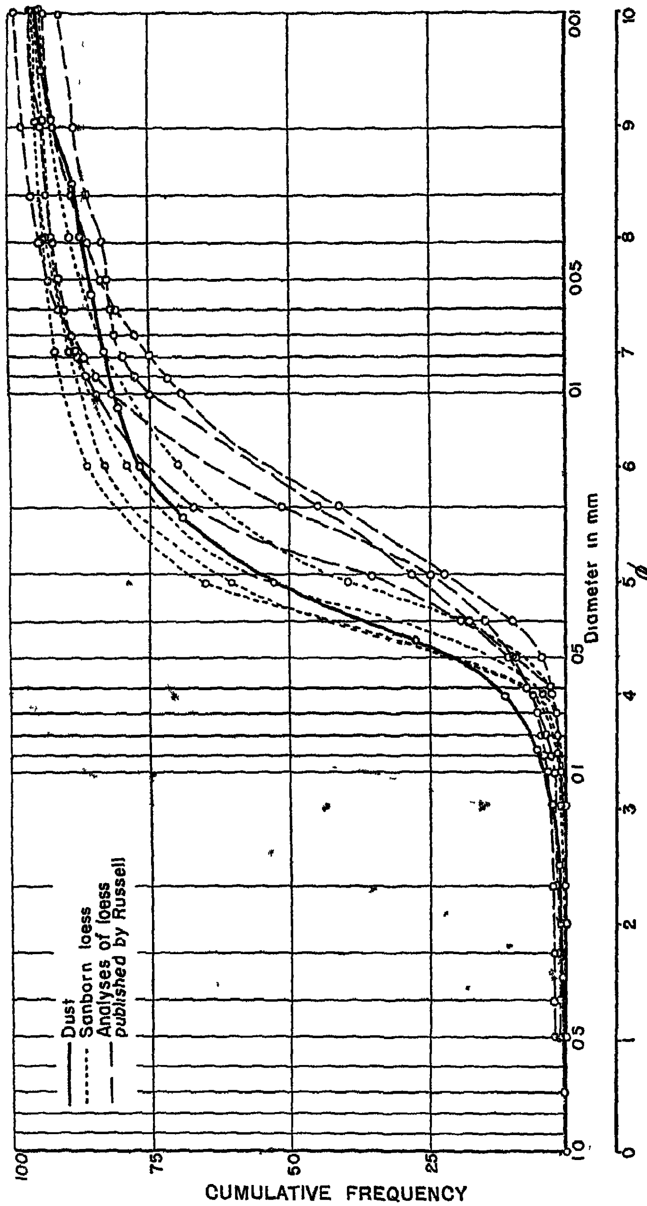

FIG. 1. Cumulative curves of four analyses of Sanborn loess (Sample Nos. 1, 5, 10, 12); four loess analyses published by Russell; and an analysis of modern wind-deposited dust.

of shape of the curves representing the analyses of loess to the curve obtained from the material known to have been transported and deposited by wind is quite apparent. The curves obtained from analyses of Sanborn loess samples indicate slightly coarser material, and Russell's analyses indicate a generally finer material than the 1939 deposit.

The only significant discrepancy between the shape of the curves obtained from analyses of Sanborn loess and the eolian material is in the disproportionately large percentage in the coarse fractions shown by the dust curve. A microscopic examination of the dust, however, reveals that these coarse fractions contain a large percentage of organic material such as fragments of plants and insects and some coal dust. Although such organic materials might have once been in the Pleistocene deposits, they were not preserved. All the distributions, including the dust, fulfill Russell's requirement that at least 50 per cent of the distribution must fall between 0.01 and 0.05 mm. (Russell, 1944, pp. 4, 5).

We have chosen the quartile deviation, defined as half the range of the middle 50 per cent of the frequency distribution, as the measure of sorting for comparison because it is not affected by the ends of the distribution. The data are expressed in terms of phi units, each being equivalent to one Wentworth grade, so that conventional statistical methods can be used.

The quartile deviation for the dust is $0.79\,\phi$; that is, the middle half of the sample falls within 1.58 Wentworth grades. The quartile deviations for Russell's four loess samples range from $0.65\,\phi$ to $0.92\,\phi$, and their mean is $0.81\,\phi$. The quartile deviations for the 12 samples of Kansas loess range from $0.47\,\phi$ to $0.90\,\phi$, with a mean of $0.67\,\phi$. Thus, the Sanborn loess samples seem to be better sorted than both Russell's loess and the dust, but the dust sorting falls within the range of that of the Sanborn loess. Stress has been placed upon the range of quartile deviations rather than upon their standard error because of the small number of analyses involved in each case.

A number of analyses of Peorian loess samples from Iowa were reported in a recent paper by Kay and Graham (1943, pp. 173-183). In order to make further comparisons the quartile deviations were calculated from 18 of these analyses selected at random. The average was $0.75\,\phi$ with a range from $0.34\,\phi$ to $1\ 49\,\phi$. This range includes the sample of dust,

all of the Sanborn loess samples analyzed, and all of the loess analyses published by Russell.

A comparison of skewness values[1] also shows similarity between the dust and Sanborn loess. The dust skewness is +0.93, the average of Sanborn loess analyses is +0.96, with a range of +0.78 to +1.14; and the average skewness of Russell's loess analyses is +0.41.[2] The skewness of a "loess-like" material described by Russell as a Pleistocene terrace remnant, is −0.07, which is much smaller and in the opposite direction. Although little is known about the significance of skewness in sediments, analyses of loess samples almost uniformly show a strong positive skewness.

The discrepancies between the sorting and skewness values of the Kansas loess and Russell's loess may be in part the result of differences in preliminary treatment of the samples. The effect of thorough breaking up of the coarse aggregates of the Kansas loess samples by a rubber pestle would be to increase the skewness and improve the sorting. Breaking up of clay aggregates or granules may tend to destroy some characteristics of the loess deposit as it occurs in nature, but it is believed that this did not affect the conclusions. Aggregates of grains were rare in the dust.

CONCLUSIONS.

The comparisons that have been made of the grain size analyses of Kansas Sanborn loess, of loess deposits along the lower Mississippi valley, and of Peorian loess in Iowa with an analysis of material known to have been transported and deposited by wind show that there are no important differences. These data seem to demonstrate that wind can be competent to sort material to the degree represented by some loess deposits.

[1] The skewness formula used is Pearson's $Sk = \frac{3(M-Md)}{\sigma}$, where M = arithmetic ϕ mean, Md = ϕ median, and σ = ϕ standard deviation.

[2] In order to compute skewness values from Russell's data it was necessary to estimate hypothetical geometric distributions from his cumulative curves Inasmuch as the points on the curves were numerous, the error introduced should be small.

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LOESS TYPES AND THEIR ORIGIN.

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ABSTRACT. Loess is widespread in the southern part of European USSR and extends through the Kirghiz steppe to Lake Balkhash and farther northwest to Yakutia Different types of loess are distinguished: primary loess of aeolian origin and secondary loesses, redeposited and originated by other processes Degraded loess and compact stone-loess are also recognized. Dust from which primary loess originated is believed blown by anticyclonic winds from fluvioglacial alluvium of glaciated areas and foreglacial deserts, and deposited over adjacent prairies. In distinction from this "cold" loess, the other, "warm" primary loess has been blown from the exposed mountain ridges and foothill thallus of Central Asiatic Mountains and adjacent deserts, and deposited in the surrounding prairies, but part of the dust in these areas was also blown in from the distant areas of glaciation.

An alternative, soil-hypothesis of loess ascribes its origin to soil-forming processes from any fine-grained formation deposited by water in foreglacial and foothill alluvial plains Comparative petrographic, chemical, and mechanical analyses of different types of loess give little support to this hypothesis, and the true water-laid loesses have greater compaction and offer more resistance to pressure than does the typical, porous, wind-blown loess.

The secondary loesses are more widespread than the primary loess, but are much thinner than the latter.

Richthofen's aeolian theory is emended by elucidation of the part which deserts played in origin of loess dust. Obruchev's critics point out that the Sahara desert is not surrounded by belt of typical loess; however, dust from Sahara is constantly carried away to the Atlantic and the Mediterranean, and is the original material of loess in Algeria, Tunisia and Tripoli The Nile Valley and Arabia to the east are unsuitable for dust accumulation. The whole of equatorial Africa presents climatic conditions very different from those of east-central Asia, where yellow loess is widespread, and in places is underlain by a more ancient reddish loess, which, beside the color, differs also by having greater clay content and lesser porosity.

LOESS and loess-like rocks are widespread in the south of the European part of the USSR. They cover the Ukraine almost to the shores of Black or Azov seas, and stretch along the northern foothills of the Caucasian Mountains. Toward the north they make tongue-like penetrations toward the towns Vitebsk and Moscow, and also along the right bank of the Volga River to Kazan.

In the Asiatic part of the USSR they cover the southern half of the Kirghiz steppes (prairies) and the foothills of the Altai, and spread out between the Caspian and Aral seas to Kopet-Dagh Range and from there stretch to the plain of Syr-

Daria River and to Lake Balkhash. They cover also the slopes of the Tien-Shan and Pamir-Alai ranges, and spread over Fergana and Ili valleys. They are encountered also in the eastern half of Minusinsk Basin, near Irkutsk, in the southern zone of Trans-Baikalia, and in the north between Nizhni Vilui and Lena Rivers, and westward and eastward from the town Yakutsk on Nizhni Aldan River.

Russian investigators now recognize two kinds of loess, which differ in origin and in characteristic features: (1) typical loess, which could be called *primary loess*, and (2) clay-like loams, sandy loams and sands, which may be grouped as *secondary loess*. The primary loess is an aeolian formation, while the secondary loess is either the result of redeposition of primary loess by water, or is an alluvial and deluvial fine-grained earthy formation, which acquired its loess-like characters by weathering and soil forming processes. The primary loess can, on the other hand, lose its typical properties *in situ*, in which case it is called *altered* or *degraded loess*.

In central Asia an ancient loess has been found; a compact marly rock, frequently schistose, and with insignificant porosity. This rock is called stone-loess.

Most Russian students believe that loess in European Russia and Siberia is a direct consequence of Pleistocene Glaciation. They postulate that widespread ice sheets were centers of anticyclonic winds which blew down the ice-free adjacent plains. Numerous streams and flooding glacial waters ran to these plains, and these carried gravel, sand and mud, and deposited them to form what we call fluvioglacial alluvium. Intense thaw during warm seasons caused their overflow; during cold seasons they were in retreat, and left behind them wide areas covered by loose friable deposits. As the anticyclonic winds blew they were raising from these deposits quantities of fine sand and dust. Similar materials were blown also from exposed grounds and from frontal morains, eskers, kames and outwash plains. From these wide areas of peri-glacial deserts the winds carried the dust far into the adjacent steppe, where it was deposited over the wide watersheds, well covered by herbaceous vegetation; under protection of this vegetation the settled dust became converted into loess formation. Along the glacial

streams, which traversed this steppe, banks were exposed at their retreat during cold seasons and these became sources of local dust, to be added to that brought from greater distances. Because of this the loess near such banks is coarser grained than farther away from them. The loess which was thus formed from sources created by glaciation may be called *cold loess*. Another loess type, *warm loess*, was formed in the past, and is still being created by the deserts and semiarid parts of the continent, particularly along vast territories of Central Asia. The ample areas from which wind raises quantities of dust are the bare surfaces of mountain ridges and hills, lose talus along their foothills, salty flats and flat shores of lakes exposed during their drying in summer, fall and winter seasons, and the banks of rivers, which become exposed and dry when waters retract after flowing far into deserts at times of maximum overflow. An important part in raising dust is played by the small blowouts formed in great number in the hot time of day upon the plain. As hot air moves up above them, it sucks the dust from the surface and raises dusty whirlwinds high into the air. The winds which, in the fall, winter and spring blow away from the deserts of Central Asia, are generally directed toward the south, east and west and so they carry the dust to the margins of these deserts. The heavier sand particles are deposited first and form loose sands, while the lighter particles are deposited in the surrounding steppes, where they accumulate under cover of the herbaceous vegetation and form loess. The sandy areas in the marginal parts of the deserts are being continuously stricken by winds and present an additional source of dust, which is raised and carried to the steppes. In this manner were formed the thick beds of primary loess in China and western Manchuria, and on the northern slopes and foothills of Nan-Shan and Kuen-Lung, northern and southern foothills and slopes of Tien-Shan. In all the slopes and foothills of these Ranges and others in Central Asia, materials of "cold" loess play an insignificant rôle at the present, but during glacial epochs much of it was added to the material representing "warm" loess. Thus in the primary loess of these areas certain quantities of local material—from mountain ridges, scattered sands, and fluvial and lacustrine deposits—were added to exogenic material carried in from far away.

In 1915 another hypothesis, the so-called soil-hypothesis, was offered in Russia, which has had and still has many sup-

porters.[1] According to this hypothesis any fine-grained deposit may be converted into typical loess as a result of weathering and soil forming processes. The formation thus produced and simulating loess, consists of an accumulation of lime acquiring a granular structure in consequence of the coagulation of minute colloidal particles to larger ones and to rather stable dusty and fine grained aggregates. Original stratification disappears and porosity characteristic of loess is produced. The advocates of this hypothesis hold that the chief factor involved in transportation and deposition of the loess-forming material is running water both in peri-glacial and foothill alluvial plains, where this water carries in and deposits eluviated material of which typical loess is formed.

Detailed petrographic study in connection with chemical and mechanical analyses of various loesses showed, however, that loess-forming processes can neither produce the calcium saturation characteristic of loess, nor explain the inertness of colloidal (alumosilicate) and carbonate parts to each other in the same loess. Besides, as erection of large buildings upon loess in the Ukraine shows, the loess, when saturated with water, becomes condensed under load and subsides, causing deformation in the heavy buildings. The fact that this tendency toward subsidence is observed only in primary loess proves that they were not deposited by water and never were thoroughly and intensely soaked in it—that is they were accumulated gradually in dry steppes from dust brought in by winds and not by water.

In regard to origin it would be necessary therefore to distinguish (1) primary (or typical) loess, cold and warm, an aeolian product, the material for which was brought in from periglacial and inner deserts, and deposited upon dry steppes; and

(2) Secondary loess, consisting of different loess-like clays, loams, sandy loams, which represent alluvium, talus, proluvium, as well as primary loess redeposited by water; all of these were to greater or less extent a subject of loess forming processes and acquired certain, but not all, characteristics of loess.

Secondary loesses are much more widespread than the primary ones. They are frequently encountered in the zonal devel-

[1] This explanation has recently been advocated by R. T. Russell for the loess of the lower Mississippi Valley See Geol Soc. Amer, Bull. vol. 55, 144, pp 1-40. Ed

opment of primary loess alongside with the latter, but their thicknesses are limited to several meters, while that of primary loess is usually up to ten, twenty, and not infrequently to forty or fifty, and in China even to one or two hundred meters. According to Richthofen, the originator of the aeolian hypothesis, Central Asia was almost completely covered with loess, which filled the valleys and hollows between the mountains, and was produced as a result of the weathering in the mountains, the loess-forming material from these being moved downward by water and wind. Obruchev has observed that in central Asia there is no loess: it appears only in the marginal zones. His observation of the distribution of loose sands and loess along these marginal zones made it possible to emend the theory proposed by Richthofen and so to elucidate the part played by the desert as a source of dust and sand. Antagonists of this theory point out that the vast Sahara desert is not surrounded by a belt of typical loess. They forget, however, that the red dust from the Sahara is carried away by winds blowing westward to the Atlantic (as it has been observed to settle on sailing ships since long ago), and northward to western Europe, as well as forming loesses in Algeria, Tunisia and Tripoli. In the East the desert is bordered by the Nile Valley where dust blown in becomes mixed with alluvium and cultural soils. Still farther eastward lie the Red Sea and the Arabian desert, which are unfavorable for dust accumulation. Southward from the Sahara stretches the equatorial zone which is rich in atmospheric precipitation. In general, the climatic conditions in northern Africa are quite different from those observed in Asia. Regions convenient for accumulation of a thick dust formation, so common there, are almost absent here. Nevertheless, here too loose sands occupy great areas in the western, northern, and eastern margins of the desert.

In China the beds of primary yellow loess are underlain in places by beds of reddish loess, which is distinguished from the yellow variety by greater clay content and lesser porosity These beds are frequently covered by a layer of gravel. This older loess was probably deposited in early Quaternary time when in Central Asia took place an extensive outwash and blowout of the higher territory beds, where the red beds of the upper Cretaceous and Tertiary continental deposits occupied considerable areas in hollows between the higher ground. From these areas the reddish dust was brought to China and accumu-

lated to produce the older loess, which since has become a subject of intense degradation *in situ.* Locally it is underlain by darker red clays with Pleistocene faunas.

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DISCUSSION.

Thorp: Regarding the loess in China, some of the reddish color in the older loess is probably due to the soil-forming processes that were active after older beds of loess were formed and before younger deposits were made.

Bryan: Obruchev made argument for formation of loess in northwest China, southeast of the Ordos Desert, but I believe it is essentially glacial in character. The loess blown from the Ordos Desert was probably due to periglacial climatic effects (i.e., strong anticyclonic winds). There are known to have been more extensive glaciers in the mountains of Tibet than exist there at the present time.

To the answer by Thorp to Bryan's remark: The loess-like rocks of southern China seem more likely to represent not the recent, but rather the older "cold" loess, which is connected with the ancient glaciation of Tibet, and subsequently degraded under the very moist recent climate of southern China. At such climatic conditions the eolian loess cannot be formed, but instead various kinds of red soils (krasnoziem) are usually developed.

Elias: Some processes, generally called "soil processes," are supposed to be responsible for both building up and deterioration of loess. To say "soil processes" is not enough; we must be more specific.

OBRUCHEV'S ANSWERS TO REMARKS.[2]

To James Thorp: If we assume that the reddish color of the more ancient Chinese loess resulted from some soil processes then we should postulate for the time of its origin much warmer climate accompanied by greater humidity. However, a simpler explanation of the reddish color of the ancient loess is fur-

[2] Submitted in written form after the meeting

nished by the wide development of the red Tertiary and upper Cretaceous deposits in central Asia, which are now largely covered by the yellow Quaternary deposits, and which were the source of the ancient loess. Besides, moist climate is generally unfavorable for the origin of loess.

To KIRK BRYAN: The greater thickness (to 400 meters?) of the loess, which is to the south of Ordos, is directly at its border, that is to the south of the sands, and diminishes farther to the South. If this loess were a "cold" one and had originated in connection with the glaciation of Tibet, which, by the way, is fairly distant from this country, then its thickness would have been on a decrease in the opposite direction: from the south northward. Besides, this hypothesis leaves without explanation the occurrence of the large area of Ordos sands to the north of the thick loess. In European Russia the sands are located between the southern border of glaciation and the area of the development of the loess, which is a natural consequence of the proximal deposition of the coarser material by the anticyclonic winds, while the dust has been carried farther away. Thus in China the sands should have been deposited to the south of the loess, closer to the border of Tibet, if it were a "cold" loess.

To M. K. ELIAS: In order to explain what is meant by "soil processes" a special report would be necessary, which the author could not furnish because of not being a specialist on soils. Much attention has been devoted to this question in the recent Russian literature.

SIGNIFICANCE OF LOESS IN CLASSIFICATION OF SOILS.

JAMES THORP.

ABSTRACT. The soils developed from loess vary considerably because of great variation in combination of factors involved in soil formation: climate, biological activity, relief and time. Besides, the character of loess, which is the parent material, also varies considerably Drawing of the boundaries of types of soils in the soil survey of the Great Plains is helped considerably by the understanding of loess origin, thickness, and distribution Many problems in soil classification and mapping are intimately connected with the problems of origin of different portions of the loess which is called summarily Sanborn in Kansas and Peorian in Nebraska Thus the work of the soil scientist here, as well as elsewhere, is that on surface geology

Suggestions are made for field research on loess and for collecting of loess and soil samples in the Great Plains area.

THE study of soils is fundamentally a problem in surface geology. For practical reasons the classification of soil is made in such a way that the limits of taxonomic and cartographic units will have significance to land use. Soil classification is the meeting ground of agricultural science and geology.

As stated in the 1938 Yearbook of Agriculture, "Soils are natural media for the growth of plants They are mixtures of fragmented and partly or wholly weathered rocks and minerals, organic matter, water, and air, in greatly varying proportions, and have more or less distinct layers or horizons developed under the influence of climate and living organisms."

The most commonly recognized factors of soil formation are: (1) parent material, (2) climate, (3) biological activity, (4) relief, and (5) time. With many variations in each of five chief variables in soil formation, one can see at once that the possible number of combinations is very great indeed, even where the parent material is the only variable. Loess may be considered as parent material, but more accurately it is a kind of parent rock from which parent material develops through leaching and hydrolysis. Even if all loess were exactly the same character it is easy to see that the number of soils developed from it would be very great if the other four factors varied individually or in groups. Actually, however, not only does each of the factors vary greatly from place to place, but

the character of loess also varies considerably. A multiplicity of soil types is the result.

Climate is of chief interest, in soil formation, in its effectiveness, in promoting hydrolysis and leaching of soils and soil materials, and, more important, in its effects on the growth and distribution of plants and animals.

The direct effects of relief are chiefly those having to do with moisture relationships, including run-off, run-on, surface accumulation, and infiltration of water. Indirectly, soil-moisture differences due to relief affect soil characteristics through biological activity.

The effects of time are conditioned by other factors. The same period of time will not always produce the same result in soil formation. A long exposure of soil material and soil in a humid climate will result in greater extremes in leaching, hydrolysis, and horizon development than in a very dry climate, which was brought out clearly by Vanderford and Albrecht (1942). It must be remembered, of course, that the age of soil will also depend on the rate at which geological erosion is removing soil material. In some areas the removal is so rapid that the soils are kept in a continuously youthful stage of development. In areas where dissection is very slow or nil, soils are able to attain a ripe old age.

Since we are dealing with loess as a factor in soil formation, we must know what we mean by the term loess. A search of geological and soil literature indicates that there is no complete agreement among scientists as to what should be called loess. It seems to be accepted by a majority that aeolian origin is one of the primary requisites, although there is no complete agreement even on this point. Probably this is because it is not always possible to determine whether or not a deposit had this origin. For use in the soil survey, the following very tentative definition and discussion have been prepared recently by Doctor Baldwin, Chief Inspector of the Division of Soil Survey. He has consulted a number of men in the preparation of the statement and there is still some disagreement regarding certain features of it.

"Loess—An unconsolidated or weakly consolidated deposit of calcareous fine earth material, dominantly silt throughout, with a lesser content of very fine sand or clay, or both. Each deposit is practically homogeneous as to mechanical composition. The mineral composition of loess is variable, depending on the source of material,

but there is everywhere an appreciable content of calcium carbonate or calcium-magnesium carbonate. Most of the material effervesces in cold dilute hydrochloric acid, indicating the presence of calcium carbonate. Secondary nodules (concretions) and tubes of calcium carbonate are present in many deposits. Most geologists and geomorphologists now agree that true loess deposits have been accumulated by the action of wind; in fact an aeolian origin (mode of accumulation) is regarded as a definitive feature. Residuum from loess is generally very silty, although deposits of loess high in clay-forming minerals, weathering in humid climates, may form residuum with a relatively high proportion of clay. In humid climates free carbonates are leached out to considerable but variable depths, depending upon the kind and the degree of impress of the factors and processes of weathering. Some confusion has arisen among soil scientists owing to failure to distinguish between geological formations or deposits properly called loess, and very silty residuum which may or may not have been formed by the weathering of loess. Distinction should be made between loess and dune sand, on the one hand, and between clayey wind-laid deposits, or 'clay dunes' on the other."

The important features brought out by this definition are: (1) That loess should include a definitely limited range of particle-size composition and (2) that a clear distinction should be made between loess and the weathering products of loess, including the soil profile. One point about which there has been considerable controversy is the matter whether loess should be defined as always containing appreciable quantities of calcium and/or magnesium carbonates. Some soil scientists feel that some unstratified silty deposits, presumably of aeolian origin, never had appreciable quantities of these minerals. However, it is also true that our surveyors have seldom found very deep deposits of this sort which were noncalcareous throughout.

A great deal of the material from which soils have developed in the forested and prairie regions of southern and western Indiana, Illinois, and Iowa presumably is of aeolian origin and originally would have been classified as loess. The thinner parts of these deposits have been strongly weathered and no longer bear characteristics usually associated with loess. Good examples of this are in the claypan soils developed from aeolian silts of southern Indiana, Illinois, Iowa, and eastern Nebraska. Where the original aeolian deposits were thin the original calcareous material, if ever present, has been leached almost

completely from the soil and the material now contains a rather high percentage of clay and a relatively low percentage of silt-sized particles. Where the original deposits were deep and where they have not been removed by dissection, some of the deeper materials still contain much of the original character of the loess, including various percentages of calcium and magnesium carbonates. Throughout this area the character of soils developed from loess or loess-like material varies from shallow dark-colored silty soils over calcareous loess to thick heavy-textured soils with very heavy claypan subsoils. In *forested areas, the soils are light colored and strongly acid in* reaction In the humid prairies, they range from light to dark colored and from approximately neutral in reaction to very strongly acid. In the Great Plains the reaction is usually neutral or alkaline and the color of the soil is dark in the eastern part and progressively lighter colored westward from subhumid into semiarid regions.

The work of Guy Smith (1941) of Illinois shows that soil age and geological age of the same aeolian deposit are not synonymous throughout the extent of that deposit. For example, he found that the age of soils adjacent to the bluffs of the Illinois River on uneroded loessial uplands was less than on the same deposit of loessial material a considerable distance from the river bluffs and the supposed source of the loess deposit. He assumed that the former flood plain of the Illinois River provided the silt of which the loess is composed. Where profile development has kept pace with deposition of aeolian silts, we can say that no loess has ever existed in this place. Briefly, Smith's explanation is that the rate of soil development in the loessial material, distant from the source, was approximately equal to the very slow rate of deposition. Adjacent to the bluffs, the loess accumulated so rapidly that leaching, hydrolysis, and soil formation could not proceed as rapidly as the material collected. For example, the total thickness of aeolian deposits many miles from the source might be approximately two feet; while the total thickness on the river bluffs might be 20 or 30 feet. The soil distant from the source is one of the clayey texture and strong profile development, while the one on the bluffs has much less clay and does not have such a strongly developed profile in terms of eluviation and illuviation.

Theoretically, it is possible for a soil surveyor to recognize a soil type purely on the basis of its physical profile character-

istics and to draw boundaries on the basis of observations made at regular intervals. This is practically as well as theoretically possible, but mapping by this method is slow and cumbersome, especially because of the fact that within any local area we have soil profile differences which are due to factors other than the character and thickness of the parent material. These differences correspond closely to local relief as it has influenced moisture relationships and the distribution of vegetation. When field research is able to bring out relationships such as those explored by Smith, it facilitates the work of the surveyor to the extent that it gives him a theoretical basis on which he can draw boundaries around areas of soil observed in individual excavations. If we know the probable source of loess, we may expect to find the thickest deposits of it near that source and we can expect progressively thinner deposits outward from the source in the direction followed by winds during the period of deposition. Most soils grade almost imperceptibly from one type to another and the surveyor is frequently at a loss as to where to draw his boundaries. A knowledge of the distribution and thickness of parent loess and a working theory regarding its origin will help the surveyor to decide where to draw his boundary lines.

Within a given climatic and vegetative zone, as in the Brown-soils zone of eastern Colorado, we sometimes find subzonal differences in soil profiles developed from loess which are difficult to explain and hence difficult to delineate, especially where one subzone grades into another. It appears, for example, that soils developed from loess and loess-like materials in southeastern Colorado average somewhat more clayey, both in surface soils and subsoils, than in east-central Colorado. What is the reason for this difference, and, therefore, where is the most logical place to draw our boundary lines when soils of one group grade into soils of another group? Is the loess or loess-like material of southeastern Colorado actually heavier textured than that farther north? Is there a difference in the age of the material, or is there a mineralogical difference in the character of the loess that causes the genesis of more clay in southeastern than in eastern Colorado? Is there an actual difference in the percentages of clay, or are apparent differences due to the chemical characteristics of the clays?

Another question that has not yet been answered fully has to do with the number, sequence, and geographical extent of loess

deposits on the Great Plains. How many separate deposits of loess were made during the period that has been classified collectively in Kansas as Sanborn and in Nebraska as "Peorian"? How complete was the coverage by loess by each one of these deposits? Where are the areas of old soils that were not covered by the more recent loess deposits? These and many other questions might be posed, and we think that our field research in soils is gradually bringing to light some of the answers. Mr. Williams' adjacent paper is an attempt to suggest an answer regarding the relative ages of certain soils in western Nebraska, and the extent to which a part of that area was covered by the most recent of the "Peorian" loess deposits.

We know that more than one buried soil exists in some of the deposits of Peorian loess. We have strong evidence that some of these intra-Peorian soils were never buried or at least were buried to only a shallow depth by more recent aeolian and alluvial deposits.

One of the puzzling problems that confronts the soil scientist is the existence of areas of Holdrege soils in regions where Keith soils are dominant. Keith soils of the Chestnut great soil group are characteristic of a dryer climate than Holdrege soils of the Chernozem great soil group. Evidences observed in Chase County, Nebraska, indicate that the Holdrege soils there were formed before the last deposition of loess and were not completely buried by it. They are darker colored and deeper than the adjacent Keith soils and they occur in a position that suggests that part of them were covered by loess deposits from which the Keith soils have developed. This suggests that the soil developed before the last loess must have been formed under a climate somewhat more humid than the present one because we do not find soils as dark-colored that seem to have developed under present climatic conditions in Chase County.

Following are some suggestions regarding the type of research that we think would be of help to the soil scientist.

1. It would be helpful to study complete cross sections in undissected areas of recognized loess throughout the Great Plains at regular intervals in each direction. Complete descriptions should be made of the sections and mechanical analyses should be made of samples collected from each distinct layer or horizon. It would be very helpful if samples of loess from each site could be studied to determine the approximate

content of quartz, clay-forming minerals, calcium and magnesium carbonates, and heavy minerals.

2. Care should be exercised in the collection of samples to see that they were all taken under similar relief and drainage conditions. Details of local differences caused by differences in relief, drainage, and vegetation could be worked out by more detailed surveys.

3. It would be desirable to collect samples of weathered rocks and alluvium from areas where there is no present loess cover, both in river valleys and on the uplands, to determine whether the mineralogical and textural patterns worked out on the loess have any relationship to areas that are not covered by loess.

4. It is felt that soil scientists might be able to contribute something to the study of buried soil profiles in relation to archeological and paleontological studies. Field research in the loessial area of the Great Plains might be done on a cooperative basis in which contributions would be made by representatives of all branches of natural science. Botanists, ecologists, paleontologists, archeologists, geologists, physiographers, geographers, and soil scientists, all working together on the same general problem, should be able to come up with better answers to scientific and practical problems than representatives of any one of these disciplines working individually.

To repeat, soil science is fundamentally a branch of geology. The work of the student of soils can be of greatest practical usefulness only when it draws on the disciplines of geology, geography, biology, agronomy, chemistry, and physics for supplementary information and interpretation. To my way of thinking, there should be no dividing line between so-called "scientific" and "practical" investigations. All scientific investigations on soils, loess, or any other geological phenomenon, should eventually have some practical significance to land use in its broadest sense.

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DISCUSSION.

STOUT: In Chase County, Nebraska, in blowouts in the deeper soils, one finds elephant fauna associated with artifacts. In western Nebraska one finds an old bluish-black, marly sort of soil material and the same elephant fauna. I agree that the coöperation of all agencies is desirable to clarify exact relationships. "How many soils are we dealing with?"

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SEQUENCE OF SOIL PROFILES IN LOESS.

B. H. WILLIAMS.

ABSTRACT. The time factor or age of soils developed from loess in western Nebraska appears to be expressed in the character of the present soils There is sufficient evidence to suggest that the soils on the tableland south of Chappell, Nebraska, have developed from loess of two distinct periods of deposition. The Dawes soils developed from the older loess or silty, loess-like alluvium apparently had reached the stage of mature normal soils before the second or last loess deposit was made Evidence supporting this belief is contained in the fossil soils buried beneath the last loess from which the present zonal soils (Keith series) have developed

Where the old soils were not buried and have remained at the surface through the second period of loess deposition and soil formation they have developed strong claypan subsoils, an indication of their antiquity or of accelerated soil-forming processes The compact claypan subsoils of the Dawes soils are in contrast with the friable, medium-textured subsoils of the Keith soils which contain only slightly more clay than their surface soils Since the Dawes and Keith soils south of Chappell have developed from similar friable, silty materials and occupy comparable physiographic and topographic positions, and since the soil-forming influences on them probably have been the same during the period which has given rise to the normal Keith soils, it seems reasonable to suppose that the claypan of the Dawes soils is a result of soil-forming processes operating over longer periods than necessary for the formation of Keith soils The soils buried beneath the most recent loess have characteristics much like those of the Holdrege series (Chernozem) Where these soils have not been buried they appear to have been advanced to the development of claypan soils (Dawes series)

THE Peorian loess of Nebraska, as stated by Condra and Reed (1) includes all the dust deposits of post-Loveland age. It comprises the initial Peorian (post-Iowa) and probably also equivalents of loess substages found between the Wisconsin drift sheets in South Dakota, Iowa, and Illinois. Some study of the loess substages has been made, but these have not been correlated as yet.

It is the current opinion of both soil scientists and geologists that the dark bands or buried soils—fossils soils—in the Peorian loess mark more humid climatic intervals separating the more xeric loess substages. The buried soils represent all stages of soil development from the youngest, most immature soils to the normal zonal soils and Planosols (claypan soils) of the present.

No attempt is made in this paper to correlate the buried soils with the established Pleistocene stages or substages, or

loess depositions, or to estimate the amount of time required for development of these soils. The purpose is to record some observations on similarities and differences between these and the present soils, and also, where the old soils have not been buried, to bring out their relationships to the soils that have developed on the younger loesses.

The observations recorded here were made over a three-day period in November, 1943 in the course of a routine inspection of the soil conservation survey of Deuel County, Nebraska. They are taken from field notes compiled for later use in correlating the soils of the county. The observations are more or less applicable to all of Deuel County, but they relate more specifically to an area of 10 or 12 square miles around a point about three miles southwest of Chappell, Nebraska. This area represents the undissected part of the tableland which Wolfanger (2) calls the south divide and describes as an ancient terrace built at the confluence of the South Platte River and Lodgepole Creek.

The terrace lies about 150 feet above the flood plains of these streams and 25 to 50 feet below the top of the Ogallala which outcrops a short distance to the west and forms the westward extension of the table. The outcrop of the Ogallala includes the Kimball member of this formation, and the algal (*Chlorellopsis*) limestone described by Elias (3) as the topmost bed of the Tertiary in Kansas and adjoining states.

The high elevation of the terrace in relation to the top of the Tertiary column places it as the first or second post-Ogallala terrace and probably of early or middle Pleistocene age.

With the great amount of dust being deposited in western Nebraska near the close of the terrace-forming period, it is reasonable to assume that considerable wind-borne material was deposited on the terrace in the later stages of its formation when it was covered by grasses. This would account in part for the silty texture of the soils and the loess-like character of the three to five feet of fine-earth material immediately above the gravelly alluvium over which the oldest soils are developed.

During the more humid cycle following the formation of the terrace, the soils that formed on the nearly level areas of the tableland apparently were undisturbed for a long period of time and they developed profiles equivalent to the present Chernozem soils and associated weak Planosols. The relatively dry period following the first soil-forming period was one of erosion, and

than the associated normal soils. Therefore, it would seem logical to conclude that soil-forming processes operating slowly over long periods, as in the Dawes soils south of Chappell, would tend to give very similar or like profiles on the same kinds of parent materials that the processes would give if operating rapidly for a much shorter period, as in the Dawes silt loam of Kimball County, Nebraska.

The Keith soils include friable granular silt loam soils developed from yellowish-gray silty loess (B) in areas where the loess is four or more feet thick. In the upper part, their subsoils are friable silty clay loam, having cloddy or prismatic structure, and in the lower part they are friable silt loam and have little structure development. The increased heaviness in the upper part of the subsoils can be determined in the field only through close comparison with the other layers; whereas, the corresponding layer in the Dawes soils contains a very notable increase in content of clay.

The upper parts of the profiles of the Sherman soils (A2), Dunlap soils (A3), and Goshen soils (A4) have developed from the most recent loess, and in this respect they are like the present normal Chestnut soils but the lower parts of their profiles include the old fossil soils (C2) or have developed in part from the fossil soils.

The Sherman soils do not differ from the Keith soils to a depth of 20 to 36 inches, but below this depth they rest on or include the fossil soil and their lime-carbonate horizons have formed in part, if not entirely, in the dark organic-bearing layer of the fossil soil. The subsoils of the buried soils may be within the zone of influence of the soil-forming processes now operating, but in many places they lie deeper than this.

The morphology of the Dunlap soils is not so easily explained as that of the Sherman soils. From their general make-up, they appear, however, to include the old soils which were more or less eroded and then received a thin layer of younger loess —about 12 inches thick—all of which has become darkened with organic matter. This addition to the dark layers of the fossil soil gives the Dunlap soils thicker organic-bearing layers than the Keith and Sherman soils.

Although the Dunlap soils are comprised largely of the old soils, and the weathering and soil-forming processes have continued in the old soils as long as in the Dawes soils, their subsoils show only semiclaypan development about equal to

that of the fossil soils that are buried deeply. The writer thinks that the strong claypan did not develop in the subsoils of the Dunlap soils because the thin mantle of late loess in the soils above them absorbed all or nearly all the impacts of weathering and soil-forming processes, and thus little weathering and alluviation of the lower layers have taken place. This explanation would seem plausible because just as in the Keith soils which have developed entirely from late loess, there has been little downward movement of clays from the surface layers.

The Goshen soils are comprised largely of dark-colored local alluvium that has accumulated in depressions and swales in the undissected uplands and at the foot of slopes along the drainages. The soils are dark and of rather uniform texture and consistence. They have little structure development except where the local alluvium is thin, and the lower parts of their subsoils include the heavy layers of the fossil soils.

DISCUSSION.

Bryan: I am much pleased to see the principles of stratigraphy applied to the study of soil phenomena and am glad to know that soil scientists realize that soils as we now find them are the result of different sets of soil-forming processes operating at different times. One set of soil-forming processes may be superimposed on soils formed under another set of processes and the results are far from simple. I feel that there is a good possibility that a fairly definite chronology can be developed for glacial and post-glacial deposits, using soil profiles as an important means of determining this chronology.

Thorp: Mr. Pate and I have been making some field observations on the growth of gullies in loess and in soils developed from it. In many instances, a deep vertical-walled gully is formed at first and the walls of the gully gradually recede uphill in a sort of wave. As the walls recede they become progressively lower and the land below each wall is a fairly smooth slope. New gullies form in the gentle slopes below the old gully walls and wave after wave of the walls can be traced uphill from intermittent drainageways. The resultant slopes of the drainageways comprise a series of smooth slopes and "cat-steps." We recognize, of course, that some "cat-steps" in the loess region are due to other causes. A parallelism may be drawn between the phenomenon here described and the super-

imposition of one set of soil-forming factors on another set. Many of our old soils as we now find them are the products of several "waves" of combinations of soil-forming processes. The effects of the earlier waves may be and usually are obscured by the effects of later waves and it becomes very difficult to reconstruct the history of many of these old soils. The interpretation of buried or fossil soils is somewhat less difficult. It seems fairly safe to assume that each of three buried post-Tertiary soils and the present soil have been subject to less complicated sequences of soil development than one early post-Tertiary soil that may have been exposed at the surface continually since, perhaps, Kansan times.

PATE*: Regarding buried soil profiles—most examples of this are in the western part of the loess belt. Buried profiles have a tendency to be quite local and occur in areas of erratic or frequently changing climate. As to the equilibrium of profile development, there is a wonderful opportunity to study this in North Dakota where we have soils developed on the residual parent material west and south of the Missouri River and on the younger glacial material north and east of river. Within short distances of each other and under similar climatic environment soils appear to have reached very similar stages of maturity indicating they have reached an equilibrium.

* Soil Conservation Service, U. S. Dept. of Agriculture.

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INFILTRATION INTO LOESS SOIL.*

F. L. DULEY.

ABSTRACT. Tests were made in both field and laboratory to determine the infiltration rate for loessial soils. The results indicated that when these soils are bare they seal over during rains and have their intake rate reduced in the same way as other soils. The intake rate can be greatly increased by covering the surface with a straw mulch. The effect of the mulch was much less on the raw, parent material of the Peorian loess, due to the fact that it has not developed as stable structure as has the surface soil. This absence of a well developed structure and shortage of binding material also leads to excessive erosion on this soil.

LOESSIAL soils, particularly those formed from the more recent deposits, are generally considered to be open porous soils. It might be inferred, therefore, that they should absorb water rapidly. The texture of the material is intermediate or mostly of silt size, and the profiles of most of these recent deposits are strikingly uniform and do not show the results of development that are common in many soils.

The surface layers of the loess soils, such as the uneroded Knox, Marshall, or Hastings soils, have developed dark surface horizons. The structure of the surface soil has been greatly altered from the original loessial material.

EXPERIMENTAL.

In work here on soil and moisture conservation, determinations have been made on the infiltration rates of loess in comparison with other soils. The field tests were made on plots 6.6×33 feet, or 1/200 acre. Water was applied by artificial sprinkling at approximately 1.5 inches per hour. Infiltration tests made on small, isolated plots usually give intake rates higher than the intake rate under field conditions. Therefore, the data from these plots represent the capacity of the surface soil to take in water rather than the rate at which it might be absorbed during natural rainfall when the water would be falling over an entire watershed, and where the subsoil after becoming filled with water could exert greater effect in reducing the intake rate.

* Contribution by the U. S. Department of Agriculture, Soil Conservation Service, Office of Research, and the Nebraska Agricultural Experiment Station, cooperating. Journal Series No 357.

TABLE I.

The total water intake and infiltration rates of different soil types on bare cultivated soil with a slope of 4 per cent.

Soil type	Total intake water in 90 minutes First day	Total intake water in 90 minutes Second day*	Infiltration rate at end of 90 minutes First day	Infiltration rate at end of 90 minutes Second day
	Inches	Inches	In per hour	In per hour
Knox silt loam	1.05	0.58	0.38	0.21
Marshall silt loam—eroded phase	1.08	0.43	0.42	0.21
Marshall silt loam—heavy subsoil (A-slope)	2.43	0.38	0.28	0.21
Marshall silt loam—heavy subsoil (C-slope)	1.07	0.37	0.41	0.17
Butler silt loam	1.32	0.57	0.38	0.25
Butler silty clay loam	1.24	0.37	0.30	0.16
Pawnee clay loam	1.20	0.76	0.50	0.33
Dickinson sandy loam	1.37	0.48	0.40	0.24
Lancaster sandy loam	1.71	0.61	0.68	0.32
Mean	1.39	0.51	0.42	0.23

* The second test was made on day following first test.

A summary of the results obtained on nine different soils or locations is shown in Table I (from Duley and Kelly, 1939). These figures indicate that the intake of water by loessial soils in a cultivated and bare condition is very similar to the rate for the other soils tested. The similarity of the results from the two groups of soils is much more striking than their differences.

Other tests were conducted to compare the water intake where the cutivated soil surface was protected by a covering of straw with that where the soil was cultivated and left bare. The results are shown in Table II.

Whenever any of the soils were protected by a covering of straw, the amount and rate of water intake was maintained at a much higher level than when the soil was bare. This has been found to be due to the formation of a compact surface layer when raindrops fall on a bare soil (Duley and Kelly, 1939).

To maintain a high intake rate it is necessary to keep this compact surface layer from forming so quickly. This can be done by placing some type of cover, such as straw over the surface. When this is done, somewhat greater differences in the soils are brought out. As shown in Table II, the soils with heavy surface soils and claypan subsoils finally showed a reduced rate of intake as compared with the silt loam or sandy loam soils. This reduction did not occur, however, until the heavy soils had absorbed water in excess of expected rainfall in Nebraska.

Later work in the laboratory has shown that the raw Peorian

TABLE II.

The intake of water by different soil types as affected by straw mulch in comparison with cultivated bare surface.[1]

Soil type	Character of subsoil	Surface condition[2]	Duration of application[3]	Total water applied	Total intake	Infiltration rate at end of application
			Hrs	In	In	In per hr.
Knox silt loam	Silty, uniform	Straw mulch	15 9	28 52	24.58	0 98
		Bare[4]	9.3	13.85	5 90	0 25
Marshall silt loam —heavy subsoil phase (A-slope)	Silty clay	Straw mulch	14.0	28.39	24.46	1 20
		Bare	9.6	15.33	6.27	0 21
Butler silty clay loam	Claypan	Straw mulch	13 5	41 14	21.89	0 50
		Bare	7.0	12 47	2.74	0.15
Pawnee clay loam	Claypan	Straw mulch	10.6	34 31	20.17	0 38
		Bare	7 0	10.93	4 85	0.29
Dickinson sandy loam	Silty clay	Straw mulch	6 5	20 29	11.12	0.48
		Bare	4 0	7.01	2 23	0.24
Lancaster sandy loam	Sandy, uniform	Straw mulch	12.8	45 83	28.89	0.92
		Bare	4 7	8.09	3.48	0.32
Mean		Straw mulch	12 21	33 08	21 85	0 74
		Bare	6 92	11 28	4 25	0 24

[1] These plots of mulched and cultivated land are not directly comparable so far as time of application is concerned, but water was applied on each plot until the rate of infiltration became approximately constant.

[2] All plots spaded and raked until in about the condition of a garden bed. Some were then covered with straw and others left bare.

[3] Water applied during several hours on two or three successive days.

[4] These results from a plot with only an 0 85 per cent slope All other plots reported in this table were on 4 per cent slopes.

much of the area of the original soils was eroded to varying depths. In some places the soils are entirely removed and the underlying gravelly alluvium was exposed. Some of the old soils, however, remained intact and most of these remnants were buried by later deposits of loess in which the present soils are forming. This loess deposit had the effect of partially smoothing out the inequalities of the previous erosional surface and is of unequal thickness. It rests disconformably on the old soils and Pleistocene gravel beds.

On the basis of the above we have a composite Pleistocene geological column from the youngest to the oldest as follows:

1. Post-loess soils.
2. Loess.
3. Fossil soils.
4. Thin loess or silty loess-like alluvium.
5. Alluvium, chiefly arkosic sand and gravel.

Figure 1 presents a hypothetical composite cross section showing the geological and soils relationships on the tableland south of Chappel, Nebraska.

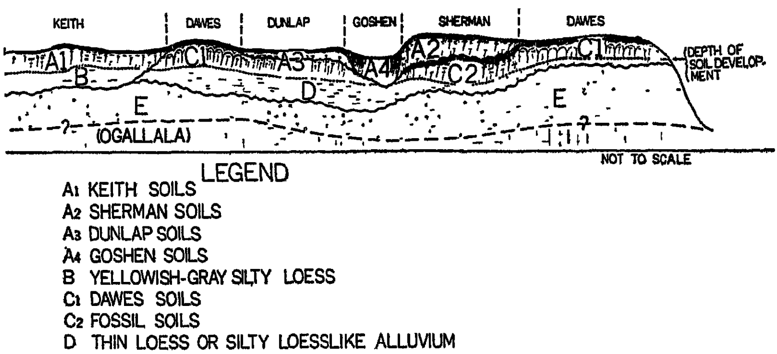

Fig. 1. Hypothetical cross section on tableland south of Chappell, Nebraska.

The fossils soils (C2) (see Fig. 1) bear evidence of a more humid climate than that of western Nebraska at the present time. They have thicker and darker organic-bearing layers, more compact clayey subsoils with more pronounced structural development than the present normal soils, and they are

leached of their carbonate of lime to a greater depth. These fos-sil soils are about representative of the Chernozem group of soils of central Nebraska, and include profiles that correspond to those of the Holdrege and Hastings series, normal soils and Half-Planosols, respectively.

In places where the old soils were not buried (or were buried only to slight depths) by the later loess, weathering and soil-forming processes have continued to operate on them through two periods of soil formation and one period of erosion and loess deposition. Much clay has been formed and accumulated in their subsoils to produce strongly developed claypans with columnar structure characteristic of Solonetz soils. It seems possible that these Solonetz-like soils may have developed without the sodium saturation and the imperfect drainage generally considered necessary for the formation of Solonetz soils.

The claypan soils were included with the soils of the Dawes series (C1) in the original classification of the soils of Deuel County and they are retained in this classification, at least tentatively, in the present soil conservation survey. As a whole, these soils have nearly level relief, but in places they are on slopes of two or three per cent gradient and occupy more sloping areas than some of the adjoining normal Chestnut soils of the Keith series (A1) which have been developed in a relatively short period, during and since the deposition of the most recent loess.

The formation of the Dawes soils on slopes is in contrast with the Dawes silt loam in Kimball County, Nebraska, described by Jackson, Hayes, and Weldon (4), regarding which they state: "The Dawes soils occur in position where external drainage is poorly developed but where water seldom stands . . . The topographic position of this soil shifts the balance between the other developmental factors, giving, in a sense, an old soil." From the above it is assumed that the Dawes soils described by Jackson, Hayes, and Weldon have developed under a soil climate (soil moisture and biological relationships) different from that of the normal soils of the same general area, and that the processes of soil development either were speeded up sufficiently to give a soil of much more advanced stage of development than would be expected for the time the processes were operating or the processes operated longer than assumed.

The Dawes soils south of Chappell are in a position no more favorable, and in places less favorable, for rapid development

loessial material, which contains very little organic matter, and has been obtained at a depth of ten feet below the surface, does not take water as readily when exposed at the surface as does the dark surface soil.

TABLE III.

Effect of organic matter within the soil or on the surface on rate of infiltration by loessial soil (McCalla, 1942).
Length of tests, 1.5 hours

Loess soil material	Treatment	Intake of water —Inches: First test	Intake of water —Inches: Second test*	Intake in inches per hour at end of: First test	Intake in inches per hour at end of: Second test
Parent material (Peorian loess)	None	1.57	0.77	0 54	0 44
Top soil (6 inches)	None	1.63	0 86	0.69	0 55
Parent material	Straw, 4 t per A.	2 38	1.31	1 04	0 76
Parent material (Manured)	Straw, 4 t. per A.	4.27	2.32	2 54	1 46
Top soil (6 inches)	Straw, 4 t per A.	5.50	2 46	2 90	1 62

* One day after first test.

The relative intake of this loessial subsoil material and the dark virgin surface soil when bare and when covered with straw were given in Table III. These figures indicate that the parent material when exposed at the surface did not absorb water rapidly, and they also show that even the top soil when bare took in water but slightly more rapidly than the subsoil. This was due to the formation of a compact layer at the surface. However, when the two were covered with straw, the subsoil settled down to a considerable extent and the rate of intake was decreased more rapidly than was that of the top soil. Because of the more stable structure of the surface soil, it maintained a high intake rate for considerable time provided it was protected from direct action of raindrops. The difference in the stability of the structure of the parent material and the virgin surface soil may be easily demonstrated by placing a lump of each in water and observing the extent and more rapid rate at which the parent material breaks down. This lack of a stable structure of the parent material, together with an absence of fine plant roots, which do much to bind the

soil together, indicates why the parent loess material is so easily eroded and trenched by gullying once the surface plant cover and the top soil are removed.

SUMMARY.

It appears from these results that the loessial soils studied have shown no special properties which allow them to absorb rainfall water at rates higher than those for many other soils. When covered with straw all soils tested absorbed much greater quantities of water than when bare. The loess subsoil when exposed and subjected to rainfall quickly lost much of its capacity to absorb water rapidly, even when covered with straw. The bare top soil sealed over quickly, but when covered with straw maintained a high intake rate for a longer period of time. However, in both the bare and covered condition, the top soil of the loess had infiltration rates strikingly similar to the other soils tested, even though some of them were radically different in texture, parent material, and profile characteristics.

In order to utilize as fully as possible the subsoil of the loess for deep penetration of plant roots, such as with crops like fruit trees or alfalfa, it is necessary to keep the surface of the soil protected by residues or otherwise in condition to absorb most of the rainfall. Even then it may not be possible at times to apply as much water as the plant could use.

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CHARACTERISTICS AND USES OF LOESS IN HIGHWAY CONSTRUCTION.

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ABSTRACT. Some of the properties of loess which are important in highway construction are described and discussed Special physical tests of "soils," which include loess, and which have been standardized by engineers, permit identification of their types and their expected performance as building material Disturbances of soils due to exposure in cuts and to various subsequent engineering operations have important effect on their properties. There are also some regional variations in loess properties in different sections of Nebraska, which are indicated by a series of tests Performance of loess in subgrades, as binder in stabilized base courses and filler in bituminous surfacing are described

THE knowledge of methods of classification of soil as developed by soil scientists or pedologists has been used more and more during the past twenty years, and now, it has been found almost indispensable in highway soil surveys. Highway engineers today generally agree that soil studies are a very essential part of the engineering required in highway design and construction.

Although soil is one of the oldest and most complex of the construction materials, the engineer knows the least about its physical and mechanical properties. He has considerable knowledge of most of the principal materials of construction, can usually find accurate and extensive physical data concerning them, and, generally, can predict with confidence how these materials will perform in a given structure. However, he cannot find corresponding data concerning soils, nor can he predict with certainty how a soil will perform in various structures.

SOIL SURVEYS AND TESTS USED IN HIGHWAY DESIGN.

The Nebraska Department of Roads and Irrigation is charged with the responsibility for the construction and maintenance of the highways of the State. During the early activities of the Department in the construction of low-cost roads, systematic soil studies were inaugurated, in an endeavor to gather general and specific information concerning the characteristics of soil which are related to highway construction. A progress report, Bulletin No. 6 of the Nebraska State-Wide Highway Planning Survey, was the first publication concerning these soil studies.

The general procedures followed by the Department of Roads and Irrigation in conducting soil surveys and performing the identification tests are described in the Methods of Tests of the American Association of State Highway Officials (A.A.S.H.O.) and in Bulletin No. 6 by the Highway Planning Survey. These surveys entail the field identification of soils, sampling, location of areas which carry surface and underground water, and observations of road subgrade conditions and of soil conditions adjacent to highways.

The most important uses of the soil survey in the design of grades and surfacing are to determine: (A) The requirements for compaction of embankments. (B) The necessity of subsurface drainage and its extent. (C) The location and extent of undesirable subgrade soils. (D) The most suitable types of surfacing. (E) The thickness of the surfacing required. (F) The location of acceptable local material deposits for surfacing and bases. Other uses of the soil survey are in landscaping, erosion control, and in foundation engineering.

SOIL TESTS.

Many soil terms and identification tests are common to the soil scientist and the engineer. Many of these tests have been standardized by engineers through organizations such as the American Association of State Highway Officials and the American Society for Testing Materials, and standard procedures for these tests are found in the publications of these organizations.(1) These procedures differ from those used by soil scientists so much that comparable results may not be obtained when the same soils are tested by the two groups. Some of these are Mechanical Analysis, Atterburg Constants, Centrifuge Moisture Equivalent and Shrinkage Tests. Other tests made by the highway engineer and similarly used in the evaluation of soils are the Tri-Axial Compression Test, Shear Test, California Bearing Value Test, Consolidation Test and the Compaction Test.

EFFECTS OF SOIL DISTURBANCE.

The construction of highways affects the natural soil body and the structure of the soil by creation of a number of disturbances, though these sometimes are not apparent. These

disturbances create additional problems to those already encountered in nature. Some of these are as follows. The disturbed and recompacted soil often has a much lower shear strength than the undisturbed soil. The construction of a high embankment causes considerable consolidation of the undisturbed natural soil under the embankment. The construction of impermeable and semi-permeable pavement on subgrades and the densification of the soil in cuts and embankments interferes with the normal evaporation and creates seasonal transient water tables. Snow removal operations on bituminous surfaced or black-top roads leave snow on the shoulders. This causes differential temperature conditions in the soil under the shoulders and under the surfacing. The melting snow results in saturation of the road bed and potential frost damage. Drainage problems are often created by intercepting permeable layers of soil which rest on less permeable layers. Deep excavations made for bridge abutments and piers create settlement problems.

MAJOR MANTLE AND BEDROCK AREAS IN NEBRASKA.

From the point of view of the highway engineer the existing division of Nebraska into seven major areas of mantle and bedrock formations is suitable. When working in these areas he will know, to a varying degree of accuracy, the probable type of material which would be encountered in highway construction. These seven regions are Bottomlands, Sand Hills, Glacial Drift Areas, Loess Uplands and Terraces, Clay and Shale Areas, the Mixed Area and Tableland Areas on Sandstone.

The Sand Hills and The Loess Uplands present the most uniform soil conditions of any of the regions as far as the highway engineer is concerned. These two areas include a total of approximately 50,000 of the 77,000 square miles in Nebraska. The Loess Uplands comprise approximately 30,000 square miles, and the loess is quite a common material used in the construction of highways.

EXTENT AND VARIATION OF LOESS.

In general, throughout the Loess Uplands and Terraces, excavations made in hills during highway construction do not penetrate through the Peorian Loess blanket. On the flat uplands the Loveland Loess is seldom exposed. The glacial

drift area, located in the eastern part of the state, has been covered with loess deposits but erosion has removed much of them leaving in some places only loess-capped hills. Highway excavations in southeastern Nebraska frequently cut through the loess caps on hills and expose bedrock and glacial deposits. These abrupt changes present different problems than those encountered in the loess in the Loess Uplands and Terraces. The loess is also often mixed with glacial materials during grading operations.

The physical characteristics of the material in the loess blanket are quite uniform. However, there is a tendency toward higher clay content, higher plasticity index, and lower sand content as the distance from the sand-hill area increases. The loess in the bluffs along the Missouri River may be an exception. These tendencies are based on studies of soil profiles encountered in highway planning surveys, which were made both before and after publication of Bulletin No. 6.

The Loess underlying soils of twelve series in twenty-four counties in Nebraska were included in the study of the variation of physical properties of the loess. Four arbitrary zones were established, with an increasing distance from the geographic center of the Nebraska Sand Hills. Figure 1 shows the location of the zones, the limits of which are somewhat generalized.

Table I shows the average of tests of the Loess underlying each soil series in each county which was included in the study. The average tests of loess were obtained for each county, and all county means were then averaged for each zone. The average test values for a county which is cut by a zone line were used in the mean zone values for the zone in which the greater area of the county is included. The mean zone values for per cent sand, per cent silt, per cent clay, and the plasticity index are shown in Figure 2.

The test values used in the construction of this chart are comparative and not absolute. If an attempt is made to correlate these values with test values from other methods of test some differences may be found. In the tests shown on this chart the silt is generally lower and the clay content is generally higher than in tests performed by other organizations. This may be due to degradation of the sample during mechanical dispersion.

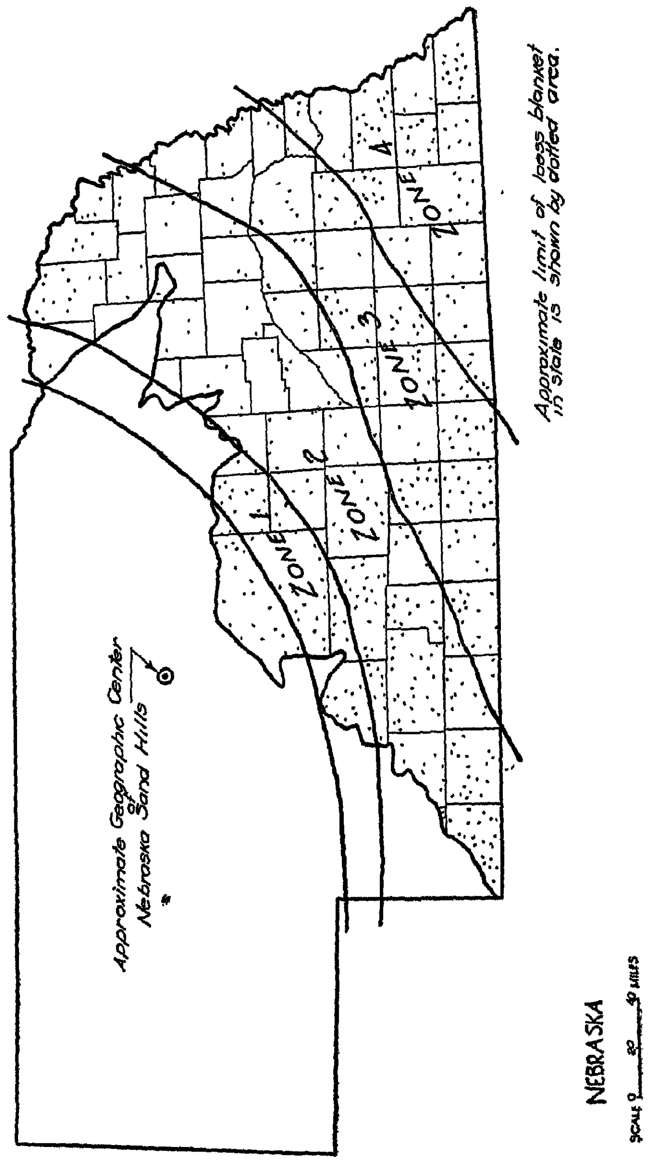

Fig. 1. Location of zones used in determining variation of loess in state of Nebraska.

TABLE I.

Physical Properties of Peorian Loess Underlying Various Soil Series in Certain Counties in Nebraska.

Soil Series	County	Mechanical Analysis: % Retained on No. 200 Sieve			Sand			Silt			Clay			Colloids			Liquid Limit			Plasticity Index			Source and No. of Tests
		Max	Ave.	Min	Max	Ave.	Min.	Max.	Ave.	Min.	Max	Ave	Min	Max	Ave.	Min	Max	Ave.	Min	Max.	Ave	Min.	
Butler	Nuckolls	2	1	0	14	13	12	59	58	56	30	29	28	15	14	13	38	37	36	13	12	11	3 L
Butler	Clay		0		13	10	7	63	55	51	38	35	28				40	38	33	18	16	13	4 F
Butler	Butler	2	1	0	15	14	13	63	58	53	33	28	23		19*		36	35	34	11	10	9	1 L, 1 F
Crete-Grundy	Clay	4	2	0	13	10	6	66	60	55	38	30	23				40	36	32	16	14	11	24 F
Crete-Grundy	Nuckolls	4	2	0	17	13	10	65	60	55	32	27	22	16	12	9	40	35	30	16	13	11	5 L, 8 F
Crete-Grundy	Thayer	4	2	0	12	9	8	67	63	58	30	28	25	16	14	12	40	35	30	15	10	5	2 L, 2 F
Crete-Grundy	Polk	4	2	0	16	11	6	67	52	59	30	27	25				39	35	34	15	9	8	1 L, 9 F
Crete-Grundy	Fillmore	4	2	0	8	16	0	66	57	50	41	35	28		15*		46	40	36	18	12	9	3 L, 58 F
Crete-Grundy	Kearney	4	2	0	17	15	13	65	60	55	30	26	22				37	35	33	13	12	11	2 L
Crete-Grundy	Gage	4	2	0	20	11	5	64	57	44	38	32	24		16*		45	38	30	22	16	11	3 L, 10 F
Fillmore	Clay	2	1	0	12	11	10	55	54	53	36	35	34				38	37	35	17	15	14	2 F
Hall-Bearden†	Platte	17	9	2	23	15	12	64	58	50	35	27	18				38	34	29	12	8	3	17 F
Hall-Bearden	Webster	11	4	1	32	21	16	69	58	48	26	21	20	12	10	8	34	31	26	12	9	6	4 L
Hall-Bearden	Furnas		1			17			59			24			12			33			11		1 L
Hall-Bearden	Valley & Garfield	10	4	1	33	23	16	67	61	51	23	16	11		10*		31	29	25	6	4	1	2 L, 8 F
Hall-Bearden	York	2	1	0	14	11	8	57	55	53	35	34	33		18*		42	40	36	18	15	13	1 L, 2 F
Hall-Bearden	Harlan	17	9	2	31	33	17	58	52	38	31	25	20				32	27	24	11	9	7	5 F
Hall-Bearden	Harlan	16	11	9	21	17	12	62	55	45	36	29	23		14*		37	32	26	16	12	8	2 L, 8 F
Hall-Bearden	Gage	2	1	0	12	11	10	56	53	51	39	36	32	20	18	16	47	44	42	20	17	15	2 L
Hastings	Clay	3	1	0	16	11	5	67	59	56	35	30	26		13*		43	34	30	16	13	10	2 L, 13 F
Hastings	Saline	3	2	1	13	12	10	62	59	58	31	29	25				39	37	35	17	15	11	6 L
Hastings	Gage	2	1	0	11	10	9	58	57	56	34	33	32	17	16	15	43	42	41	18	17	16	2 L
Hastings	Webster	2	1	0	16	15	14	66	65	64	21	20	19	11	10	9	35	34	33	10	9	8	2 L

TABLE I (Continued).

Physical Properties of Peorian Loess Underlying Various Soil Series in Certain Counties in Nebraska.

Soil Series	County	Mechanical Analysis: % Retained on No 200 Sieve			Sand			Silt			Clay			Colloids			Liquid Limit			Plasticity Index			Source and No. of Tests
		Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max.	Ave	Min	Max.	Ave	Min.	Max	Ave.	Min	Max	Ave	Min	
Hastings	Thayer	9	2	1	34	14	10	65	59	46	32	27	20	16	12	9	42	38	29	16	13	8	8 L
Hastings	York	3	1	0	16	10	6	65	58	46	40	32	17		14*		46	39	33	18	14	10	5 L, 31 F
Hastings	Platte	2	1	0	18	15	14	60	55	48	37	30	25	20	14	11	44	40	36	20	17	12	5 L
Holdrege	Nuckolls	2	1	0	17	13	10	66	59	48	38	28	23				46	36	30	21	15	10	4 L, 9 F
Holdrege	Phelps	5	3	1	23	20	18	60	55	50	31	25	18	17	11	8	37	33	30	15	10	5	7 L
Holdrege	Webster	11	7	1	36	22	13	65	55	40	26	23	20	14	12	10	39	32	28	13	10	8	4 L
Keith	Hitchcock	10	6	2	29	26	20	56	54	51	30	20	16				32	30	28	11	10	8	1 L, 6 F
Knox	Butler		7			26			58			16						29			5		1 F
Marshall	Boone	4	3	2	14	12	10	71	66	62	26	22	19				34	33	31	13	11	9	8 F
Marshall	Madison	2	1	0	16	15	13	65	59	51	36	26	20	21	13	7	44	37	33	20	14	11	6 L
Marshall	Burt & Thurston	4	2	0	14	10	7	67	64	59	29	26	24	18	12	9	38	36	34	15	12	9	11 L
Moody	Dixon & Cedar	2	1	0	19	15	13	63	59	53	34	26	22	18	13	8	37	33	28	14	10	6	6 L
Nuckolls	Nuckolls	9	1	0	27	22	16	55	49	46	37	29	22				41	31	25	19	14	7	1 L, 9 F
Nuckolls	Gage	17	15	14	34	26	20	49	45	42	31	29	24	14	13	12	38	32	29	15	12	10	4 L
Nuckolls	Clay	32	20	4	41	30	15	48	39	30	37	31	27				38	33	29	19	14	10	3 F
Scott	Fillmore	2	1	0	11	7	5	65	55	46	49	38	27				52	42	37	21	15	10	10 F
Scott	York	2	1	0	14	12	9	57	52	44	44	36	30				41	39	33	19	15	7	1 L, 4 F
Maximum Values		32	20	14	41	33	20	71	66	64	49	38	34	20	19	16	52	44	41	24	17	16	
Average Values		6	3	1	20	16	11	62	57	51	34	28	24	16	11	10	39	35	32	16	12	9	
Minimum Values		0	0	0	8	7	0	48	39	30	21	16	11	11	10	7	31	29	24	6	4	1	

* One test only

† Listed on soil map as "Sandy Loam"

L = Lincoln Laboratory.

F = Field Laboratory

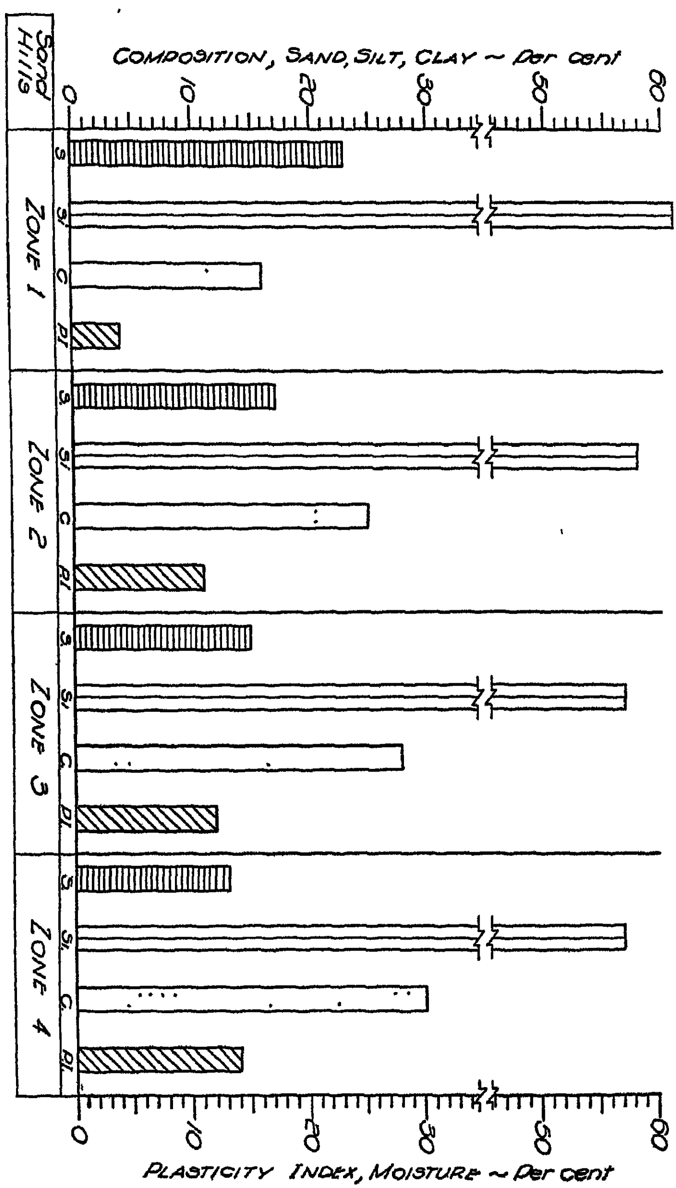

Fig. 2. Variation of sand, silt, clay and plasticity index of loess with respect to distance from geographic center of sand hills in state of Nebraska.

CHARACTERISTICS OF LOESS IN SUBGRADES OR EMBANKMENTS.

The greatest quantity of loess utilized in highway construction is used in the construction of subgrades. The average loess is considered a fair to poor subgrade material in most locations. It is classified by the Public Roads Administration's system as an A-4 subgrade soil. It absorbs water readily and softens to such an extent that it becomes unstable. It has a high rate of capillarity, especially when the silt content is quite high; and when the loess has access to water, detrimental frost heaving may occur during severe winters. This heaving causes differential vertical displacement of the surfacing which results in a rough and sometimes dangerous riding surface. Subsequent thawing results in a soft and unstable area of the subgrade which may be the cause of failure of the surfacing under normal traffic loads.

When the clay content of the loess is near the maximum and the silt near the minimum it is a more suitable subgrade material. The higher clay content reduces the rate of water intake, produces more cohesion under similar water contents and decreases the elastic characteristics. The higher clay content also maintains a more uniform water content during wet and dry cycles.

In the eastern part of Nebraska where the highway excavation frequently cuts through or nearly through the loess, many highway grades result in a soil profile containing a shallow layer of Peorian Loess which rests on Loveland Loess or glacial clay. When these latter materials have a higher clay content or a higher density than the overlying Peorian Loess they perform as an impervious horizon and prevent or retard the downward percolation of surface water. Thus a potential source of capillary water is created which may later cause detrimental frost heaving.

One of the outstanding characteristics of the loess is its ability to stand practically vertical in highway cuts and drainage channels. When the sides of a cut are sloped during construction operations the subsequent erosion of the cut slopes presents maintenance problems.

CHARACTERISTICS AS SOIL BINDER.

Soil Binder is a term describing the material which supplies the cohesion to blended mixtures known as stabilized soil base course mixtures. These mixtures are composed of soil, fine

sand, and graded sand-gravel aggregate. Loess is often used as soil binder. The aggregations of particles can be easily pulverized so that the preparation of the loess in base course construction is relatively simple. Loess which contains a high per cent of clay produces better soil binder than does loess which contains a lower per cent of clay.

The function of the soil binder is to produce cohesion and embedding properties in the stabilized soil mixture so that it can be compacted to a high density which does not change with changing water contents. The Public Roads Administration has published considerable data on the selection and use of soil binders.(2)

CHARACTERISTICS AS MINERAL FILLER.

Mineral filler is a term which describes the finely divided material passing the No 200 sieve and which is used as a stiffening agent in the asphaltic material incorporated in bituminous surfacing mixtures. Filler material is considered as that material which furnishes the preponderance of particle sizes passing the No 200 sieve. Commercial mineral filler is pulverized by grinding. Limestone dust and Portland Cement are the major commercial mineral fillers.

Loess and numerous soils are used as mineral filler in highway surfacing construction in Nebraska instead of commercial mineral filler due to their low cost and availability. The loess, which is selected for use as mineral filler, should have a high per cent of silt and a low per cent of clay in order that it will be easy to pulverize and not form clods or aggregations if it should become wet after pulverization.

The bitumen absorption of the mineral filler is a characteristic which affects the economy of its use. The absorption of the loess is the lowest of any filler except pulverized silica. Detailed descriptions of the standard tests and of special tests of filler as well as test values of many fillers including loess are reported in the proceedings of the Association of Asphalt Paving Technologists.(3)

Although the loess is the most uniform of natural construction materials there is sufficient variation in its characteristics in most profiles that it can be used for two dissimilar purposes in highway construction, that is, either as soil binder or as mineral filler, in addition to its use in subgrades and embankments.

DISCUSSION.

PATE: Size-particle distribution indicates that there is essentially an axis or focal point in the sandhills, which would suggest this as the point of origin for the loess.

BOLLEN: When making a comparison of this type, using a limited number of samples, we could not change county distribution any. When comparisons are made in different districts we get some results which appear to have certain tendencies but they seem to disappear after a greater number of comparisons are made.

PATE: The heavy soil material in the southeastern part of the state is apparently of loess origin and is farthest from the sandhills.

SCHULTZ referred to J. C. Mahr's thesis on calcium carbonate or lime content of loess which confirmed what Bollen said.

STOUT: If these data seem to indicate that much of our loess comes from sandhills source, perhaps some of this information would suggest that at least a part of our loess is from that source area rather than from a glacial source area. I wonder what percentage comes from the sandhills. I suspect that as we get toward the margins of these areas, one will find local source areas becoming more important The sandhills are perhaps one major source area of the loess.

BOLLEN: The bluffs along the Missouri River were excepted because they appeared to be quite different. Knowledge from other tests seem to indicate that this loess is somewhat different from the rest of the loess in the state.

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OBSERVATIONS ON THE PROPERTIES OF LOESS IN ENGINEERING STRUCTURES.

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ABSTRACT. Most of the studies on the physical properties of loess have been made for the purpose of determining their agronomic relationships. In the last two decades some investigators have devised methods of evaluating the physical properties of soils and loess and from the resulting information have drawn up specifications for handling the different materials to obtain the best results when they are used in engineering construction.

This paper gives some personal observations on the properties of loess and loess-like materials which affect their behavior in engineering structures. Most important of these are texture, chemical composition and the amount of moisture absorbed and held. These properties control the movement of water and the formation of ice during frost periods.

THE observations assembled in this paper are made on what is generally known as Peorian loess or loess-like material. Most of the earlier studies of loess had a purpose to determine its origin and mode of deposition or agronomic relationships of the physical and chemical properties of soils developed from it. Only in recent years specific studies on use of loess in engineering structures have begun. In the earlier studies no distinction was made between samples taken from parent loess and soil. However, it seems that many loess samples can be recognized when going through these early records.

Analysis of the earlier studies discloses moisture relationships of loess which vary with its texture and structure and the chemical composition of the colloids. These properties, when measured and evaluated, give valuable information to the soil engineer regarding desirability to use, a given loess in construction and possibility of handling or treating it in such way that its usability will be improved.

Loess absorbs and holds large amounts of water, especially when bulked or disturbed and not compacted. When saturated it may be very unstable. Moisture relationships can be measured to some extent by the Atterburg soil tests, mechanical analyses, and other laboratory tests, but it is doubtful if methods now used are the best that can be devised for determining the soil properties which affect engineering properties.

Some data on the textural analyses of loess are assembled on Table I.

The meager information furnished by the selected analyses in Table I indicates that most of the loess contains from 2 to 35 per cent of very fine sand, less than 35 per cent of clay, and 60-70 per cent of silt. This seems to agree fairly well with the analyses by Kay.[1] The four samples from northeastern Iowa and southeastern Minnesota differ radically from the

TABLE I.

Samples Location	No.	Variation in % of V F S. (0 1-0 05 mm)		Variation in % of silt (0 05-0 002 mm)		Variation in % of clay (0.002 mm)[1]	
Nebraska	11	1.8 —	8 1	61.1 —	72 3	21 5 —	33 4
S. D. Reconn.	1	2.			76 3		20 4
Colorado	2	10	10.5	67 8	69 6	19.	19 9
Kansas	3	8 2	9.	53 7	71.2	20.2	26 6
N E Iowa	2	29 4	34 4	63 4	68 4	1 4	1 6
S.E. Minn.	2	31 8	35 6	60 6	63 6	1.2	1 8
N W Iowa	3	1 5	30.7	60 7	70.6	28 7	8 5

[1] These analyses were taken from records of the Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture Exact locations are given in the records.

other samples in the per cent of very fine sand and clay. They contain about 30-35 per cent of very fine sand, 60-68 per cent of silt, and less than 2 per cent of clay. Russell's (1944) analyses for loess or loess-like materials from different places are given in Table II.

TABLE II.

General Location	Per cent Very fine sand	Per cent Silt	Per cent Clay
Germany	8	76	4
Mississippi	7	88	3
Louisiana, Sicily Is	4	88	8
Louisiana, Sicily Is (Leached Loess)..	4	91	5
Delhi, Louisiana . .	21	66	11

These samples show a generally greater per cent of silt than the samples taken in the northern part of the Mississippi Valley. Because different methods have been used for making mechanical analyses, textural analyses are not always comparable.

[1] Kay's particle-size limits cannot be converted exactly to those given in Table I

Vanderford and Albrecht (1942) included parent loess samples in their studies of a series of seven soil profiles extending from Sioux City, Iowa, to Vicksburg, Mississippi. These show a general increase in the per cent of silt and a decrease in the per cent of clay in southward direction. Their data substantiate the other textural data shown above. Vanderford and Albrecht also made chemical studies which showed a variation in base exchange capacity which was not directly related to the per cent of clay. They have rather complete chemical data on these samples but unfortunately no physical tests. From the viewpoint of the construction engineer it would be interesting to know the extent to which the physical properties of samples tested vary with the chemical properties.

Data collected by Mahr (1937) indicate that the loess in the northeastern and southwestern parts of Nebraska has a higher per cent of lime than in the rest of the state. The samples were taken at depths ranging from seven to nine feet, depending upon the depth of the loess deposit. Data obtained by the Testing Division of the Nebraska Highway Department show that this highly calcareous loess has a different physical behavior than loess containing less lime. The area of distribution of highly calcareous loess at the confluence of the Missouri and Sioux Rivers in northeastern Nebraska has a fanlike shape and the loess extends into parts of western and northwestern Iowa, southwestern Minnesota, and southeastern South Dakota. Other isolated areas are scattered over the Sioux

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EXPLANATION FOR PLATE 1.

Fig. 1. Condensed vapor rising from road backslope The dark colored zone in the backslope had absorbed sufficient heat to thaw. The air temperature was about freezing and caused the moisture vapor to rise from the warmer backslope. Same phenomenon takes place within the soil The moisture vapor which is moving from the warm to the cold area results in ice accumulation.

Fig 2. Smaller amount of vapor is rising from the lower part of backslope which is of lighter color. The vapor follows up backslope in layer This is probably due to air current caused by warm air just above soil and varies in thickness with darkness of soil and heat absorbed.

Fig 3. Dark streaks forming "V" across road are frost heaves Heave is due to loess-like silt in clay drift Inside part of "V" had been excavated and backfilled with same kind of material as found in remainder of cut. Heave is due to differential accumulation of ice in the two materials. Moisture vapor moves more freely through the silt than through the clays with smaller pores

All photographs were made in Minnesota in 1930.

FIG. 1.

FIG. 2

FIG. 3.

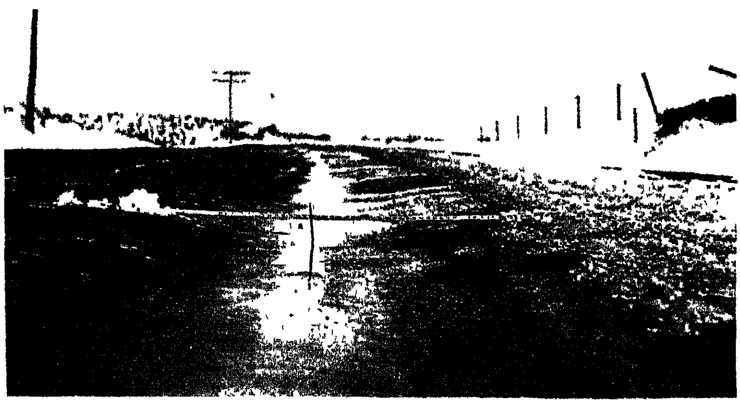


FIG. 1

One frost heave plus thawing weather and a heavy load result in a frost boil which is not in loess but in loesslike silt. The same unstable condition has been observed throughout road cuts in loess. Photographed in Minnesota in 1939.

FIG. 2.

Samples of frozen soil the fissures appearing in the photographs are ice lenses The soil is not loess but is a loesslike silt and the photographs are visible evidence of the ice formation which causes the heaving. The total amount of ice is much greater than would form from the moisture present. About 1/3 of natural size.

FIG 3.

The photographed trench was put in to drain the loess, with no success as the photograph indicates. It shows differential heaving in loess and the medium to coarse sand in the center of the trench. The pores in the sands were sufficiently large to allow for all the expansion that took place when the moisture vapor froze.

TABLE III.

Chemical Analyses of C Horizon of Loess Parent Materials of Nebraska Soils.*

Sample Number	Per cent of Colloid & Clay		Exchange Capacity	Plastic Index	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Ignition Loss	SO_3
	Colloid	25.4			54.68	7 80	20 26	2.68	2 64	2 29	.41	65	05	.19	8.46	.08
8095	Soil	31.6	21.4	20.3	67 20	3 36	12.00	2.08	4 76	2.37	1 43	.57	.05	.16	5 50	.12
	Colloid	20.1			53.95	8.42	20 25	3.14	1 49	2.28	28	75	.10	14	9 16	24
8104	Soil	26 7	23.6	14.6	71.50	4 24	12 30	1.85	1.50	2.74	1.41	.58	.08	.21	3 14	.10
	Colloid	16 6			54.79	8 31	19 92	3 19	2.07	2 15	.23	.67	06	.21	8 76	.17
8085	Soil	23 0	21 5	13.7	70.96	3 92	12 90	1 59	1.88	3 07	1 49	.58	06	25	3 47	.10

Molecular Ratio of Colloid.

	$\frac{SiO_2}{Fe_2O_3\ Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2\dagger}{\text{Total basis}}$	Plastic Index	Per cent Colloid and Clay	
							Colloid	25 4
8095	3 67	18 60	4 57	246	7.00	20 3	Clay	31 6
							Colloid	20 1
8104	3.57	16.95	4.51	.266	7 07	14 6	Clay	26.7
							Colloid	16 6
8085	3 68	17 45	4 66	.267	6 39	13 7	Clay	23 0

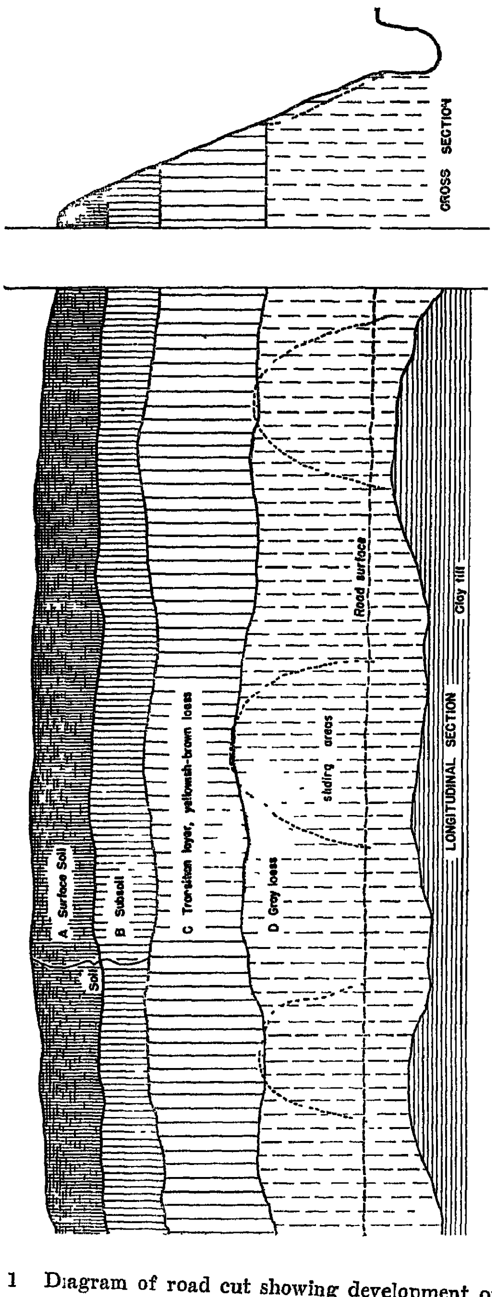
* Data from Brown, Rice and Byers (1933)
† Carbonates deducted.

TABLE IV.

Analyses of C Horizon (Parent Material) of Nebraska Soils Developed on Loess.*

Sample Number	Per cent Clay	Exchange Capacity	Calcium	Magnesium	Sodium	Potassium	pH.	Carbonate Content	Total Nitrogen	Volume Weight	Moisture Equiv	Liquid Limit	Lower Plastic Limit	Plastic Index
8865	33.0	26 0	21 1				7.8	0 1	0 030	1 24	29 7	37 8	16 9	20.9
8873		26.7	19 0				7.6		0 037		34 4	42 0	17 6	24.4
8881		27.8	C				7.0	0.1	0 034	1.33	32 9	44 7	17 2	27 5
8095†														
8889	31 6†	21.4	C				8 4	5 8	0 026		32.0	37 3	17.0	20 3
8104†														
8895	26.7†	23.6	15 6				8 1	0 1	0 025		27 8	32 1	17 5	14 6
8085†														
8902	23 0†	21 5	C				8 1	0 5	0 021		23 8	30 9	17 2	13 7
8910		27 2	18 1				7 2		0 0288	1 35	30 6	37 7	15 5	22 2
8917	35 0	29 2	19 8‡	8 5	1 1	0 4	7 2	0 1	0 033					
8925	31 2	26 2	16 3‡	7 9	1 2	1 2	7 4	0 1	0 027	1.39	30.0	35.5	14 3	21 2
8934		26 0	C				7 7	0 5	0 028	1 48	29 7	41 8	15 7	26 1
8942		25 1	C‡	7 2	0 5	1 0	8 0	2 3	0 025	1 41	29 7	36 0	16 3	19 7
8949	34 7	29.9	20 5‡	9 0	0 2	0 3	7 3	0 1	0 032	1 40	32 7	44 1	15 6	28 5
8958	34 2	24 9	15 6				6 8		0 033	1 51	30 3	44 1	14 9	29 2

* Data from Smith (1941), and Smith and Rhoades (1942)
† Data from Brown, Rice, and Byers (1933).
‡ Calcareous if figure is given less than 0 5%.
if figure is not given greater than 0 5%.



Text Fig 1 Diagram of road cut showing development of slides in the unaltered gray loess above the edge of the road trench. Vertical scale is about 15′ to 1″.

River drainage basin. There may be some relationship between the area of high-lime loess in northeastern Nebraska and the Sioux River drainage system and the old broad flood plain at the junction of the Missouri and Sioux Rivers.

The question arises, what effect does this difference in texture and in chemical composition of the colloids have on the use of loess in engineering construction. The texture bears an important relation to the per cent and size of pore space. The minerals present in the loess and especially the chemical composition of the colloids influence the physical behavior of the loess. The per cent of montmorillonite in the colloid is especially important.

The data in the tables III and IV do not seem to show any marked variation in the chemical composition of the Nebraska loess. There is, however, a decided variation in the plastic indexes of the different samples. The differences in the plastic index seem to be more closely related to the per cent of clay than to the chemical composition of the loess. These data indicate the desirability of more complete and better correlated investigation; especially desirable is more complete sampling of profile and physical analysis of more samples for which costly chemical analyses have been made.

The following observations were made in a road cut in the loessial region of northeastern Iowa in 1929, see Text Fig. 1.

The loess on the backslope was frozen to a depth of about four inches. When the temperature became warmer, thawing the frozen soil and loess, the gray loess in zone D thawed to a depth of ½ to ¾ inch and the thawed portion slid down the backslope like molasses. The amount of water accumulated as ice in the soil material above the clayey till was sufficient to produce upon thawing, a liquid mass with loss of tensil strength and stability. An interesting feature was the absence of sliding in zone C which had a light or moderate yellowish-brown color but had practically the same texture as zone D. Zone C crumbled and the small particles rolled down the slope although there was no pronounced granular soil structure as in zones A and B. The soil granules in zones A and B were loosened by thawing and also rolled down the backslope.

The one or two feet of gray loess just above the till contained sufficient moisture that it was in a liquid condition and continually flowed into the hole which was bored to examine it. The same condition has been observed in different areas

where soil materials are of similar texture, and it demonstrates how much water loess will hold where percolation is retarded by impervious or slowly pervious substrata.

When using loess and loess-like material for engineering structures it becomes apparent that methods for determining physical properties and the proper handling and treatment of the loess are essential to obtain the best results in structures. Should the loess be compacted or treated in an effort to produce granulation, or should the pore space be reduced by the addition of colloids or clays? If so, what should be the chemical composition of the clays if they are to produce the desired physical properties?

It seems doubtful that compaction would be permanent, especially in structures where the loess would be subjected to radical changes of moisture and temperature. Compacted loess, however, may prove very stable when used where climatic changes have little or no influence, as in cores for road grades, small dams, etc. If loess is used only in cores of such structures, and erosion-restraint materials are used for exposed parts, the severe effects of erosion or washing could be eliminated.

During periods of temperature changes there is a movement of moisture in the form of vapor, toward the cooler area, see Plate 1, Figs. 1 and 2. This movement of moisture vapor is greatly accelerated during freezing weather, especially when the temperature ranges from freezing to decidedly warm within 24 hours or less. Water vapor frequently escapes from holes extending through the frozen layer to the underlying moist layers. Thus, it is not difficult to understand why moisture vapor condenses and freezes under a concrete slab. Layers of ice two to four inches thick developed by this method are not uncommon. Ice is usually thickest near the joints where the temperature and air pressure variations are greatest. These variations are due to the fact that more heat is absorbed by the black joint filler and much heat is reflected from the light-colored slabs. The heaving of ice near joints in the concrete causes a rocking motion in cars driven over such a road, see Plate 1, Fig. 3. The amount of ice formed and the differential heaving that occurs vary with texture and size of pores in the materials, availability of moisture, and rate of frost penetration, see Plate 2, Fig. 3.

Observations have shown that in some places the loess or

locss-like silt in the subgrade was almost air dry three to four feet below the surface, owing to the movement of water vapor to the colder upper two to three feet adjacent to the concrete. In one place where the silt was underlain by sand at about four feet, the silt and part of the sand layer below had been almost completely dried out. Yet the upper two feet of the loess contained sufficient frozen moisture to saturate, on thawing, the dry silt and most of the sand below the frozen layer. In many instances the ice forms as lenses within the silt, see Plate 2, Fig. 2. The number of these lenses and their thickness depend upon the rapidity of frost penetration, texture of the loess, and available moisture supply. The rapidity of frost penetration itself is determined by a number of factors. Considerable experimental work on frost action has been done by Tabor (1930).

Pebbles found in several hundred soil cores which were taken during frost penetration had ice on the lower sides but none on the upper sides. This indicated clearly the character of moisture movement.

A quagmire develops whenever the ice in loess thaws, see Plate 2, Fig. 1. Thawing progresses downward most rapidly; therefore, a saturated layer exists just above a frozen layer. Loess in such places has no stability and gives way or flows under flexible road surfaces and comparatively light loads. The amount of load needed to cause the saturated loess to flow depends upon the surface covering of the road and per cent of water in the loess. Frequently, the saturated loess will flow under its own weight as may be observed on backslopes of road cuts.

It would seem desirable for all research studies made by geologists, pedologists, and soil engineers to be correlated to the end that each study will contribute information to all parties interested and duplication of effort will be avoided. Of course it is recognized that some agencies will need more detailed data than others and will doubtless need to collect supplementary information to suit their peculiar needs.

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FOSSILIFEROUS HORIZONS IN THE "SILLERY FORMATION" NEAR LÉVIS, QUEBEC.

FRANCO RASETTI.

ABSTRACT New fossiliferous localities were discovered in the vicinity of Lévis, Quebec, in rocks that have hitherto been assigned to the "Sillery formation." A 1700 feet thick section of strata in clearly recognizable order is described. At the base of this section is a shale with thin layers of limestone, containing Lower Cambrian trilobites; this horizon is designated as the *Austinvilla* zone. Somewhat higher in the section is a limestone conglomerate, whose boulders also yield Lower Cambrian fossils. Near the top of the section, thin limestone beds in the shale yielded a few fossils that appear to be of Canadian age; this horizon is designated as the *Ellsaspis* zone.

The conclusion of this work is that the "Sillery," even within the limited area investigated, includes strata that are similar lithologically, but on paleontologic evidence prove to belong to widely different ages Hence these rocks will have to be subdivided into several formations when their stratigraphy is better understood.

A new genus, *Pagetides,* eight new species of Lower Cambrian trilobites, and *Ellsaspis,* a new genus of Canadian(?) trilobites are described. The systematic position of the eodiscids is discussed

INTRODUCTION.

THE belt of lower Paleozoic rocks that crops out on the south shore of the St. Lawrence river for over 200 miles below Quebec City has not yet been assigned a precise place in the stratigraphic column. Most of these rocks are usually designated, after Logan, by one formational name, the "Sillery," although there is no convincing proof that they belong to one formation; but all the attempts toward a subdivision have remained unsuccessful(1-6).*

It now appears likely that the "Sillery" represents an assemblage of formations which, notwithstanding a remarkable lithologic uniformity, probably range from Lower Cambrian to Canadian.

Fossils had been found in place in rocks assigned to the "Sillery" only within two limited areas. Grey shales at the typical locality yield a brachiopod, described by Billings as

* Numbers in parentheses refer to the literature cited.

Obolella pretiosa and recently referred by Ulrich and Cooper(7) to the genus *Botsfordia.* According to these authors, this fossil indicates a Lower or Middle Cambrian age for the shale in question. When the use of the name, "Sillery," is properly restricted, it should be reserved for rocks that are coformational with this shale, which will henceforth be designated as the *Botsfordia pretiosa* shale. The other fossil localities lie two hundred miles to the northeast, in the region of Métis and Matane. Howell(8) has recently shown that these outcrops are probably of Canadian age.

DESCRIPTION OF THE OUTCROPS.

The section here described is exposed at Ville Guay, 4½ miles east of Lévis, on the south shore of the St. Lawrence river. A regular succession of strata begins near two conspicuous bands of conglomerate, and can be followed eastward for about half a mile. Beyond these limits, strong folding and faulting obscure the stratigraphic succession; but within the limits of the section here described, the strata maintain an approximately constant strike and dip. Moreover, none of these strata are concealed, and hence any angular unconformities that might be present could be readily observed.

The strata strike N. 32° to 35° E. (magnetic) and dip 60° to 70° to the east. The succession in ascending order is the following.

	Feet
Grey, rusty-weathering shale, with a few thin, generally lenticular beds of impure, dark grey, fossiliferous limestone (*Austinvillia* zone, fossil locality 1). . . .	11+
Conglomerate, containing grey limestone pebbles in a sandstone matrix. No fossils were observed in the pebbles..	12
Grey shale, with thin sandstone beds. .	12
Limestone conglomerate, with very little paste. Many of the boulders are abundantly fossiliferous, and contain a Lower Cambrian fauna (fossil locality 2). ..	10
Grey and green shale, with thin sandstone beds. ..	610
Alternating layers of shale and thick-bedded sandstone ..	35
Grey and green shale with thin sandstone beds . .	240
Alternating layers of shale and thick-bedded sandstone	140
Grey and green shale	110
Red, grey and green shale	360
Green and grey shale.	36
Grey shale, with six or seven layers, 2 to 3 inches thick, of dark-grey, sparsely fossiliferous limestone (*Ellsaspis* zone, fossil locality 3). . .	3
Green shale	90

Equivalent strata, but in a much more disturbed condition, are exposed across the river, on the south shore of the Island of Orléans. Here fossils were collected only from the conglomerate boulders (fossil locality 4).

AGE OF THE STRATA.

The paleontologic evidence enables one to draw conclusions only about the age of the strata at the two widely separated horizons where fossils were collected in place. The fossils occurring in the conglomerate boulders are of little use for this purpose; hence the latter fauna will not be described, excepting a few species which are interesting for their relationship with the fauna of the thin-bedded limestone at locality 1.

The fauna of the thin-bedded limestone at locality 1 includes the following species:

Austinvillia bicensis Resser.
Bonnia sp.
Pagetides amplifrons Rasetti, n. sp.
Pagetides pustulosus Rasetti, n. sp.
Periomma punctata Rasetti, n. sp.

The writer suggests the name, *Austinvillia* zone, for this horizon, since *Austinvillia* is a well-characterized trilobite, known from the Lower Cambrian of the southern Appalachians and other areas. *Bonnia* is a prolific Lower Cambrian genus of wide geographic distribution in North America. *Periomma* is also a Lower Cambrian genus. All these trilobites appear to indicate an approximate correlation with the Forteau of Labrador and Newfoundland and the Shady of the southern Appalachians, although it is possible that the *Austinvillia* zone is somewhat younger than the above-mentioned formations.

No precise correlation could be attempted even if a larger fauna were available, since little is known at present about the stratigraphic range of Lower Cambrian genera(9).

The conglomerate boulders at the localities 2 and 4 yield a large fauna. Fossils in this conglomerate were first discovered by Ells(3), and three species, *Nisusia* (*Jamesella*) *amii* Walcott, *Kootenia ellsi* (Walcott), and *Periomma walcotti* Resser, have been described. The writer has assembled a large collection of trilobites from these boulders. The following genera have been recognized: *Alokistocare, Austinvillia, Bicaspis, Bonnia, Kootenia, Olenoides, Paedeumias, Pagetia, Pagetides, Periomma, Periommella, Prozacanthoides, Ptychoparella,*

Solenopleurella, Syspacephalus, Wanneria, Zacanthoides. Several of these genera range from the Lower to the Middle Cambrian, but the presence of the olenellids proves beyond doubt that the age of the fauna is Lower Cambrian. Two of the species, *Austinvillia bicensis* and *Pagetides amplifrons,* also occur in the thin-bedded limestone of the *Austinvillia* zone, and the other species of this zone have close relatives in the conglomerate. Hence we may conclude that the boulders are at least approximately of the same age as the *Austinvillia* zone. It must be emphasized, however, that lithologically the two limestones are quite different, the boulders indicating that they were derived from a massive limestone. It is a well-known fact(10) that it has been impossible to discover the source of any of the limestone boulders of different ages that occur in conglomerates in the Lévis area and farther east on the shore of the St. Lawrence river.

There remains to be discussed the fauna of the thin-bedded limestone at the locality 3, 1600 feet above the Lower Cambrian *Austinvillia* zone. Unfortunately, the material available is very scarce and rather poorly preserved. It includes two species of brachiopods and a trilobite. Dr. G. A. Cooper, to whom the brachiopods were submitted, informed the writer that no positive identification could be attempted with the material in hand, but that the two species suggest *Orthis panderiana* Hall and Clarke and *Orthis? billingsi* Ulrich and Cooper (not Hartt). These species were described from Billings' limestone no. 2 at Lévis, and hence are probably of Canadian age. The trilobite is quite distinctive, but unfortunately belongs to a new genus and species, and it cannot be used for correlation. It is here described as *Ellsaspis elliptica,* and the horizon from which the fossils were collected is designated the *Ellsaspis* zone. It is hoped that students of early Paleozoic faunas may be able to recognize this trilobite from strata of known age and hence more definitely to determine the stratigraphic position of the *Ellsaspis* zone. It will tentatively be assumed, on the evidence of the brachiopods, that the *Ellsaspis* zone is of Canadian age. One conclusion may be drawn with certainty, *i.e.*, that the *Ellsaspis* zone is younger than Lower Cambrian, and hence the described strata are not overturned. This is important, since the "Sillery" rocks often present overturned folds, and previous workers usually were not certain in which order their sections were described.

The evidence now available does not enable one to make any definite statements about the age of the strata between the Lower Cambrian *Austinvillia* zone and the supposedly Canadian *Ellsaspis* zone. Although no angular or erosional unconformities could be observed on the section, it is likely that long time intervals are not represented.

Little can be said about the relative stratigraphic position of the strata here described and other sections of the "Sillery," since the latter are usually unfossiliferous. We do not know whether the *Botsfordia pretiosa* shale is represented in the Ville Guay section, as this fossil could not be found there. Lithology can be of little aid, owing to the uniform type of sedimentation that appears to have prevailed in this area during the Cambrian and the early Ordovician.

The general conclusion that may be drawn from the discovery of the new fossiliferous localities, is that the rocks that have been indiscriminately assigned to the "Sillery" range over a vast time interval, and will have to be subdivided, once their stratigraphy is better understood. This task will be a particularly difficult one, owing to the extreme scarcity of fossils, the complicated structure, and the unreliability of lithologic criteria.

ACKNOWLEDGMENT.

The writer is greatly indebted to Dr. G. Arthur Cooper for examining the brachiopods of the *Ellsaspis* zone and for supplying casts of types in the U. S. National Museum.

SYSTEMATIC DESCRIPTIONS.

TRILOBITA.

Order EODISCIDEA Richter.

Since the species here described bring some new contribution to the knowledge of the eodiscid trilobites, a few remarks regarding the affinities of this group seem appropriate. Several authors realized the distinctness of the eodiscids from most of the other trilobites and erected for them a special taxonomic group. Thus Jaekel(11) divided the trilobites into two orders, Miomera and Polymera, the former containing the agnostids and the eodiscids. Richter(12) and Kobayashi(13) respectively used the superfamily Eodiscidea and the suborder Agnostida in the same sense as Jaekel's Miomera. Whitehouse(14) first recognized the deep distinction between the agnostids

and the eodiscids, and while admitting the primary division of the trilobites into Miomera and Polymera, subdivided the former order into the suborders Eodiscidea and Agnostida.

Lately, students of early Paleozoic crustacea have realized that the distinction between the agnostids and all of the other trilobites is of a more fundamental nature than had hitherto been suspected, and Resser(15) first proposed that the agnostids should constitute a subclass equal in rank to the trilobites. This classification has been adopted in Shimer and Shrock's "Index Fossils of North America."

Once the agnostids have been separated from the eodiscids, there remains the question whether the latter are sufficiently distinct from the other trilobites to be placed in a high-ranking taxonomic group (such as an order or a suborder) by themselves. The writer believes that this is the case, since there appear to be no known forms to bridge the gap between the eodiscids and the multisegmented trilobites.

The Eodiscidea might be characterized as follows Small trilobites with subequal cephalon and pygidium, and two or three thoracic segments. Fixigenes generally separated in front of the glabella by a longitudinal depression Cephalic rim usually with a row of tubercles, pits or radial impressions. Animal either blind, and then lacking dorsal cephalic sutures, or possessing eyes and small libragenes of the proparian type. Pygidium usually rather elongate, with a long axis in which several segments (usually 5 to 10) are represented. Genal spines lacking; occipital spine usually developed. Stratigraphic range: Lower and Middle Cambrian.

At first sight, the distinctness of the eodiscids from other trilobites would seem to be impaired by the existence of such forms as some of those here described under the genus *Pagetides*. The cranidia of these species bear some resemblance to those of certain ptychoparid trilobites, particularly of such genera as *Periomma* which possess a wide convex rim. However, the writer believes that this resemblance is purely superficial, as it applies only to the cranidium. It must be considered that these ptychoparid trilobites have opisthoparian sutures and relatively large libragenes with strong genal spines, a multisegmented, tapering thorax and an extremely small pygidium. It is now generally admitted by students of trilobites that caudalization is a progressive character(16, 17) The fact that the eodiscids already present such a high degree

of caudalization, and corresponding reduction of the number of thoracic segments, as early as the Lower Cambrian, when most other trilobites were just at the beginning of the process of caudalization, shows that the eodiscids represent a branch that had very early diverged from the main line of development of the trilobite stock. Probably this differentiation had already taken place in the pre-Cambrian.

On the other hand, there seems to be little doubt about the homogeneity of the eodiscids. Forms that possess libragenes and eyes and forms that do not are so similar in all other respects that their close relationship is obvious. Among the suture-bearing forms, there is an almost continuous series of species that bridge the gap between the more typical eodiscid trilobites and the forms whose cranidium assumes a superficial ptychoparid aspect. The species described in this paper bring some new evidence on this point.

Thus the whole of the known evidence seems to favor the segregation of the eodiscids in a special order or suborder.

Genus PAGETIDES Rasetti, n. gen.

Small proparian trilobites with cephalon and pygidium of subequal size. Glabella narrow, cylindrical or slightly tapered, faintly furrowed, most elevated posteriorly, extended into a strong occipital spine. Fixigenes as wide as the glabella, convex, attaining their maximum relief posteriorly; separated in front of the glabella by a depression. Rim of variable width in the different species; widest in front and narrowing toward the genal angles. Rim marked with a row of more or less distinct radial impressions. Ocular ridges indistinct; palpebral lobes of moderate length, very narrow, submarginal in position, separated from the fixigenes by distinct furrows. Facial sutures directed straight to the lateral margin of the cephalon both in front and behind the eyes. Hence the libragenes (missing in all the observed specimens) must have been only as long as the palpebral lobes; their position was vertical, on account of the great convexity of the posterolateral portions of the head. The posterior branch of the facial sutures reaches the margin in advance of the genal angle by a distance equal to the length of the libragene. The narrow lateral rim is continued behind the libragene, then turns around the genal angle, without being produced into a spine, and merges with the posterior rim, which is set off by a well-impressed intramarginal furrow.

Thorax unknown. Pygidium of about equal length and width, strongly convex. Axis narrow, almost reaching the posterior margin, with five to eight segments. Pleural lobes smooth, except for the anterior intramarginal furrow; rim extremely narrow.

Genotype, *Pagetides elegans* Rasetti, n. sp.

The genus appears to differ from *Pagetia* in the longer and more distinct palpebral lobes, cephalic rim of less uniform width and with less distinct radial impressions, and in the lack of an axial spine on the pygidium.

There is the possibility that the species here described as *Pagetides* should be referred to *Hebediscus*, but the writer prefers not to do so on account of the very doubtful status of this genus. Whitehouse(14) based the genus on *Ptychoparia attleborensis* Shaler and Foerste, described from the Hoppin of Massachusetts; but he evidently had in mind the complete specimens from England, assigned to that species and figured by Cobbold(18), who referred them to *Pagetia*. Resser(19) has stated that the specimens from England and Massachusetts are not conspecific; but, as a matter of fact, from the descriptions and illustrations it is not even apparent that they are congeneric. It is likely that the English specimens represent an eodiscid; while the real *Ptychoparia attleborensis* from Massachusetts, on which *Hebediscus* must be based, may be a trilobite of ptychoparid affinities as it was originally described. Hence it is not certain that *Hebediscus* is, as Whitehouse meant it to be, a genus of eodiscids, and the present forms, which in the writer's mind are true eodiscids, are not referred to it.

EXPLANATION OF PLATE 1

Figs. 1-6. *Pagetides amplifrons* Rasetti, n. sp. 1, holotype cranidium, x8 (loc. 4); 2, 3, cranidia, x6; 4, 5, pygidia, x6 (loc. 2). 6, cranidium, x6 (loc. 1)

Figs. 7-10. *Pagetides leiopygus* Rasetti, n. sp., x6. 7, cranidium; 8, 9, top and side views of holotype cranidium; 10, pygidium (loc. 2 and 4)

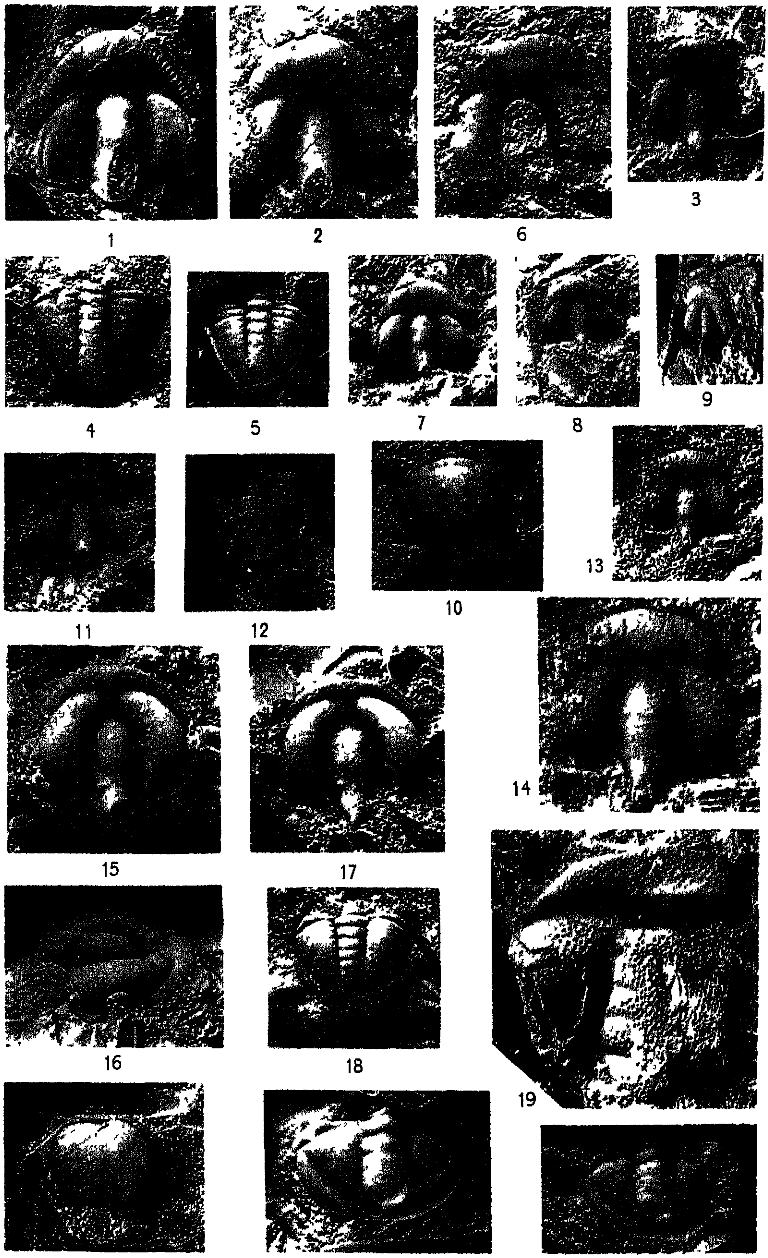
Figs 11, 12 *Pagetides minutus* Rasetti, n. sp, x6. 11, holotype cranidium; 12, pygidium (loc. 4).

Figs. 13, 14. *Pagetides pustulosus* Rasetti, n. sp. Holotype cranidium, x6 and x12 (loc. 1)

Figs. 15-18. *Pagetides elegans* Rasetti, n. sp, x6. 15, 16, top and side views of holotype cranidium; 17, another cranidium; 18, pygidium (loc. 2)

Fig. 19. *Periomma punctata* Rasetti, n. sp Holotype cranidium, x6 (loc. 1).

Figs. 20-22. *Bonnia* sp. undet., x6. 20, cranidium; 21, 22, pygidia (loc. 1).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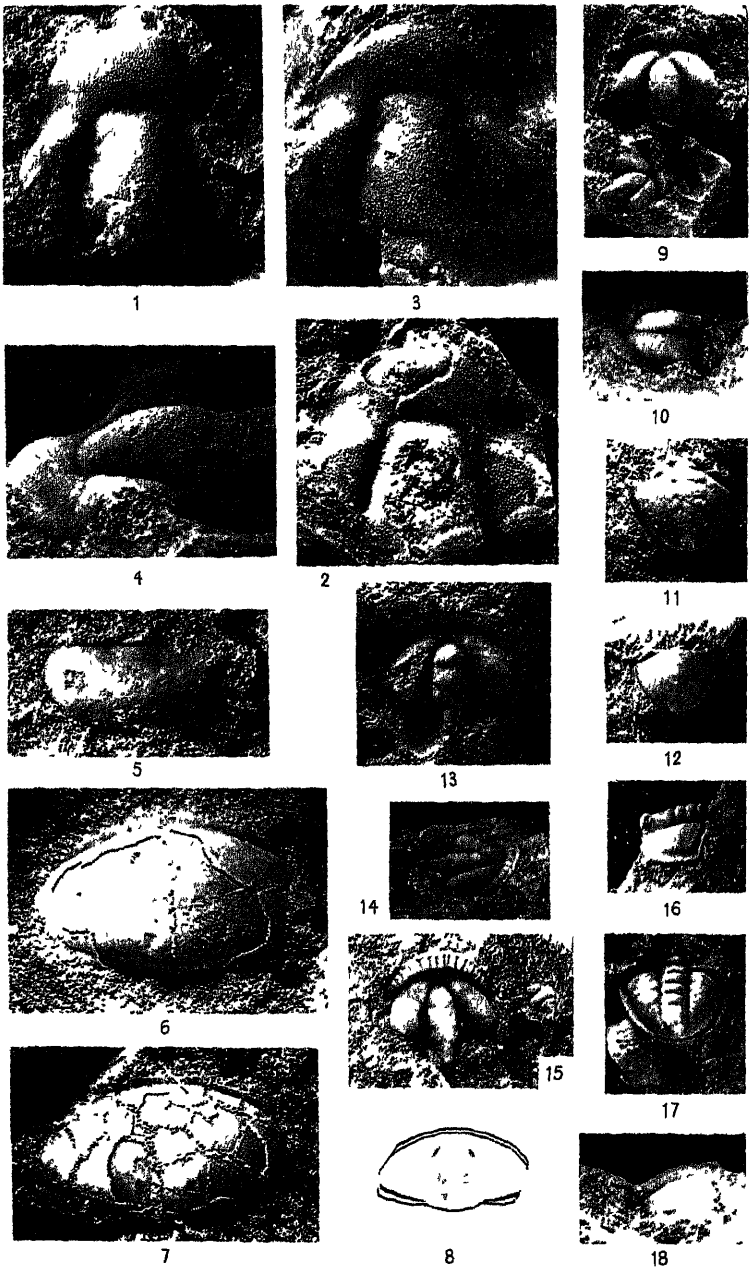
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PAGETIDES ELEGANS Rasetti, n. sp.

Plate 1, Figs. 15-18

This species is represented by finely preserved material that shows every detail of the cranidial and pygidial features. The fixigenes are strongly convex transversely, and rise as high as the glabella. They are separated in front of the glabella by a longitudinal depression that joins the anterior furrow to the dorsal furrow. The rim is rather well defined, narrow, and somewhat expands backward at the center. Glabellar and occipital furrows faintly impressed at the sides; occipital spine rather short, pointed, somewhat upturned. The side view of the holotype clearly shows the position occupied by the small, vertical, proparian libragene.

Pygidium wider than long, well rounded posteriorly. Six or seven axial furrows are visible. The dorsal furrows are deep, but the axis does not rise much above the pleural lobes. Length of largest cranidium 4 mm.

Holotype and paratypes: Laval Univ. nos. 304 a-c. Lower Cambrian boulder at locality 2.

PAGETIDES MINUTUS Rasetti, n. sp.

Plate 1, Figs 11-12

The cranidium of this form differs from the preceding species in possessing a slightly wider rim. The glabella is somewhat pointed in front, and the occipital furrow is impressed on the sides. The occipital spine is narrow, upturned.

The associated pygidium has shallower dorsal furrows than in the preceding species, and only three or four axial furrows are visible. Length of largest cranidium 2 mm.

EXPLANATION OF PLATE 2

Figs 1-4 *Austinvillia bicensis* Resser, x6. 1, 2, incomplete cranidia (loc. 1); 3, 4, top and side views of cranidium (loc. 4)

Figs. 5-8 *Ellsaspis elliptica* Rasetti, n. gen, n. sp., x6. 5, pygidium; 6, artificial cast of the holotype cranidium, a natural mold; 7, another, poorly preserved cranidium; 8, drawing of cranidium, x3, based on the above-figured specimens (loc 3).

Figs. 9-12 *Pagetia billingsi* Rasetti, n. sp, x6. 9, cranidia, the larger one being the holotype; 10, side view of holotype cranidium; 11, 12, pygidia (loc. 2).

Figs. 13-18. *Pagetia ellsi* Rasetti, n. sp, x6. 13, cranidium; 14, 15, side and top views of holotype cranidium; 16, 17, side and top views of pygidium; 18, side view of another pygidium preserving the axial spine (loc 4)

Holotype and paratype: Laval Univ. nos. 302 a-b.
Lower Cambrian boulder at locality 4.

PAGETIDES LEIOPYGUS Rasetti, n. sp.

Plate 1, Figs. 7-10

Cranidium similar to that of the preceding species, differing only in the wider frontal rim.

The pygidium that occurs associated with this cranidium is almost completely smooth, the dorsal furrows being faintly indicated and the axis hardly rising above the general convexity of the shield. Length of largest cranidium 2.5 mm.

Holotype and paratypes: Laval Univ. nos. 301 a-f.
Lower Cambrian boulders at localities 2 and 4 (holotype from former locality).

PAGETIDES PUSTULOSUS Rasetti, n. sp.

Plate 1, Figs. 13-14.

In this species, the glabella is less parallel-sided than in the preceding ones, tapering both in front and at the posterior end, where it extends into an occipital spine of unknown length. Rim as wide as in *P. leiopygus*, with faint radial impressions. Surface of fixigenes covered with small tubercles.

An imperfect associated pygidium has a prominent, furrowed axis and smooth pleural lobes. Length of holotype cranidium 2.5 mm.

Holotype and paratypes: Laval Univ. nos. 303 a-c.
Thin-bedded limestone at locality 1.

PAGETIDES AMPLIFRONS Rasetti, n. sp.

Plate 1, Figs. 1-6.

This species is chiefly characterized by the great expansion of the rim at the center. Hence the cranidium is proportionately narrower and longer than in all the preceding species. The anterior and dorsal furrows join in a fairly wide, depressed preglabellar area.

Glabella subcylindrical, almost furrowless, extended into a wide, blunt, slightly upturned occipital spine. There is just a suggestion of the occipital furrow at the sides. Ocular ridges are faintly visible on some of the specimens under proper lighting.

The cranidium of this species superficially resembles those of certain ptychoparids, but the proparian sutures show that there is no relationship with that group.

The pygidium which undoubtedly belongs to this species (as it was found associated with the cranidia in several instances) is proportionately narrower and longer than that of *P. elegans.* The axis is narrow and strongly elevated, and eight segments are represented. The first two axial furrows are well impressed, the following are visible only on the central part of the axis. The pleural lobes show a few indistinct furrows, and possess an extremely narrow rim.

Length of largest cranidium 4 mm., of pygidium 3 mm.

Holotype and paratypes: Laval Univ. nos. 300 a-f. Lower Cambrian boulders at localities 4 (typical locality) and 2. An imperfect cranidium (Laval Univ. no. 311) collected from the thin-bedded limestone at locality 1 is figured besides the types.

Genus PAGETIA Walcott, 1916.

Species of *Pagetia* have been described from the Middle Cambrian of the Cordilleran province, Kashmir, China and northeastern Australia. So far the genus has not been reported from Lower Cambrian strata, although some species occur in the earliest Middle Cambrian (*Ptarmigania* zone of the Wasatch mountains). The presence of *Pagetia* associated with Olenellids in the conglomerate boulders near Lévis therefore represents an extension of the known stratigraphic range of the genus. There appears to be no significant difference between the Middle and the Lower Cambrian forms, unless it be in the number of thoracic segments, which in the species here described is unknown.

PAGETIA ELLSI Rasetti, n. sp.

Plate 2, Figs. 13-18.

There is little to distinguish the cranidium of this form from those of certain western species, such as *P. bootes* Walcott and *P. fossula* Resser. The glabella is almost furrowless, tapering and terminates into a slender occipital spine; the occipital furrow is impressed at the sides The fixigenes are most elevated at the palpebral lobes; the small libragenes must have stood almost vertical. In front of the glabella, the fixi-

genes are separated by a wider depression than the narrow longitudinal furrow of *P. bootes* and *P. fossula*. Rim as in the western species, with a row of radial impressions. Genal angles angular but not extended into spines.

Pygidium almost identical with that of *P. fossula*. Axis strongly convex, with five or six distinct segments. There is a tubercle on each segment, and a long, somewhat upturned terminal spine. Pleural lobes strongly convex, unfurrowed.

Length of largest cranidium (exclusive of the spine) 2.5 mm., of pygidium 2 mm.

Holotype and paratypes: Laval Univ. nos. 305 a-m.
Lower Cambrian boulders, locality 4.

PAGETIA BILLINGSI Rasetti, n. sp.

Plate 2, Figs. 9-12

Compared with the preceding species, the cranidium of this form differs in possessing a less tapering glabella, and a more depressed rim.

The pygidium is remarkable for the low axis, which hardly rises above the general convexity of the shield. The axial furrows are faintly indicated on some specimens. The axis terminates into the usual spine.

Holotype and paratypes: Laval Univ. nos. 306 a-c.
Lower Cambrian boulders, localities 2 and 4 (types from the former locality).

ORDER UNDETERMINED.

Genus BONNIA Walcott, 1916.

BONNIA sp. undet.

Plate 1, Figs. 20-22.

A few pygidia and an imperfect cranidium of a species of *Bonnia* were recovered from the *Austinvillia* zone. Specific identification is not attempted, as the material is too fragmentary; however, this form is either identical with or exceedingly similar to species that occur in the Forteau and in the equivalent boulders at Bic and other localities.

The glabella has a surface ornamentation consisting of concentric ridges, as often observed in species of *Bonnia*. The posterior part of the cranidium is not preserved.

The pygidium has the structure typical of the genus. On the

outer test, only two faint axial furrows are visible, and the pleural lobes appear practically furrowless. Exfoliated examples show one or two more furrows on the axis, and faint furrows on the pleural lobes.

Laval Univ. nos. 307 a-e. Thin-bedded limestone at locality 1.

Genus AUSTINVILLIA Resser, 1938.

AUSTINVILLIA BICENSIS Resser.

Plate 2, Figs. 1-4

Austinvillia bicensis Resser, 1938, Geol. Soc. Am. Special Papers, No. 15, p. 61, pl. 3, figs. 6, 7.

Examples of this species occur in both the conglomerate boulders and the thin-bedded limestone of the *Austinvillia* zone.

The specimens were carefully compared with casts of Resser's types, and failed to reveal any significant differences. A few details may be added to Resser's brief description.

Glabella tapering, straight-sided, truncated in front. Three pairs of short, extremely shallow glabellar furrows. Occipital segment obtusely expanded, bearing a small tubercle. Fixigenes rising rather steeply from the dorsal furrows. Ocular ridges wide, made more prominent by the depression of the fixigenes anterior to the eyes; palpebral lobes small but elevated. Anterior facial sutures slightly divergent. Along the anterior margin of the cranidium, the suture is intramarginal on the ventral side, as in several genera of Lower Cambrian trilobites. Whole surface covered with fine granules. Length of largest cranidium 7 mm.

Plesiotypes from Lower Cambrian boulders at locality 4 (Laval University nos. 308 a-d) and from thin-bedded limestone at locality 1 (Laval University nos. 309 a, b.)

Genus PERIOMMA Resser, 1937.

PERIOMMA PUNCTATA Rasetti, n. sp.

Plate 1, Fig 19.

This species is represented by one imperfect cranidium. Glabella tapering, truncated in front, with three pairs of furrows faintly impressed at the sides. Occipital segment obtusely expanded in the middle. Rim wide, convex; pre-glabellar area narrower than the rim, with a faint boss in the middle. Fixigenes only partly preserved. The most distinctive feature

of this species is the strongly punctate surface of the test. Length of cranidium 6 mm.

Holotype: Laval Univ. no. 310. Thin-bedded limestone at locality 1.

Genus ELLSASPIS Rasetti, n. gen.

The characters of the genus are those of the only known species.

Genotype, *Ellsaspis elliptica*, n. sp.

ELLSASPIS ELLIPTICA Rasetti, n. sp.

Plate 2, Figs. 5-8.

Cranidium subelliptical in shape, twice as wide as long, strongly convex longitudinally and moderately convex transversely. Glabella oval, defined by an extremely faint dorsal furrow on the impression of the lower surface and probably altogether undefined on the upper surface of the test. Glabella occupying about five-sixths of the length and one-third of the width of the cranidium. Glabellar furrows probably wholly absent on the outer surface. On the impression of the lower surface, under proper lighting three pairs of glabellar furrows can be seen in the shape of oval pits; the furrows of the posterior pairs are situated about halfway between the dorsal furrows and the middle of the glabella, those of the anterior pair closer to the dorsal furrows. There also is a small pit in the dorsal furrow at each anterolateral angle of the glabella. Occipital furrow extremely shallow, defining a very narrow occipital segment.

Anterior margin of the cranidium with a narrow, flat rim of even width. Intramarginal furrow well impressed on the posterolateral limbs. The course of the facial sutures cannot be definitely determined from the imperfect material available. It is certain, however, that the libragenes, if any were present, must have been short and narrow, since there is only a short distance between the extremities of the anterior rim and of the posterior intramarginal furrow. The presence of palpebral lobes cannot be definitely ascertained. Surface of test smooth. Length of holotype cranidium 3.5 mm.

An associated pygidium is referred to this species. It is, like the cranidium, rather strongly convex and almost furrowless. The dorsal furrows are faintly indicated on the anterior third.

The writer is unable to suggest the possible affinities of this trilobite. Among Cambrian smooth forms, *Kingstonia* resem-

bles *Ellsaspis* in some respects, but has radically different facial sutures. Among Ordovician trilobites, *Ellsaspis* vaguely resembles certain Illaenids, but the shape of the glabella and of the glabellar furrows is altogether different.

Thin-bedded limestone at locality 3 (Canadian ?).

Holotype and paratypes: Laval University nos. 1250 a-c.

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CALCITRO FISHERI.

A New Fossil Arachnid.

ALEXANDER PETRUNKEVITCH.*

ABSTRACT. The discovery by Mr. Fisher of fossil arachnid remains in onyx-marble from Arizona is reported and the probable geological age given on the authority of Professor McKee. A detailed description with photographs and line drawings establishes the fact that the fossils belong to a new genus and species for which a new family Calcitronidae is proposed. The fossil belongs to the Order Schizomida known as yet only by its recent representatives.

THE present study is based upon two specimens found fossilized in calcite and belonging to the "post-faulting" period of the Cenozoic. The fossils were discovered by Mr. J. W. Fisher, President of the Southwest Onyx and Marble Company, in onyx marble pen bases cut and polished by the company. Mr. Fisher showed them to Mr. Clinton G. Abbott, Director of the Natural History Museum of San Diego, who sent me one of the specimens for study in May 1944. On learning of my interest in his discovery Mr. Fisher generously presented the specimen to me, to enable me to make a more thorough study of the fossil by having it cut out of the pen base and mounted on a slide. That specimen, the type of the new species named in honor of the donor, is now in the collection of Peabody Museum of Yale University.

The second pen base delivered in June was unfortunately damaged in transportation. It contained a centipede and was sent by me at the request of Mr. Abbott to Professor R. V. Chamberlin for study and description. Although the specimen was broken in half, it is hoped that the important diagnostic features remained intact and will furnish additional interest to the discovery of this new source of fossil invertebrates.

The third pen base containing the paratype was sent me for examination in September with the request that the pen base be returned intact. Fortunately this specimen lies so close to the polished surface of the pen base, that it can be studied without further manipulation.

Scrapings of the first pen base were examined at my request by Prof. Adolph Knopf who pronounced them to be calcite.

*(Contribution from the Osborn Zoological Laboratory of Yale University)

The extraordinary interest attached to finding fossil Arachnida in calcite and the necessity to determine, if possible, their Geological Age induced me to appeal for aid to Prof. Edwin D. McKee, Assistant Director of the Museum of Northern Arizona at Flagstaff and familiar with the region from which the pen bases came. Most courteously Professor McKee undertook the work first of locating the quarry and then determining the Geological Age of the calcite from which the pen bases were made. With his permission I quote from his letter to me, dated July 15th, 1944.

"The Bonner quarry is located in a canyon on the north side of Black Mesa, about ten miles southwest of Ashfork, Arizona. The deposit is formed in shattered and brecciated redbeds of Permian Supai formation on the down throw side of a large high angle fault. At this locality the fault has a displacement of some hundreds of feet and the Supai beds are dragged down along the north side. The fault passes under and, therefore, antedates basalt flows a few miles to the west and these are of a period I and considered to be of Pliocene Age.

"The calcite forming the onyx marble has developed largely but not entirely along bedding planes as a series of layers in which crystals are oriented at right angles to the surfaces. Individual layers of calcite crystals are in many places separated by thin films of red detrital sediment, probably dust that accumulated during periods of non-deposition of calcite. In most of the onyx marble layers there is evidence of a tendency to dome up in the centers and a resulting displacement of the red, silty shales above. The onyx marble also is developed in thin, vertical cracks and between red siltstone fragments in breccia zones. A few open cavities were noted in which stalactites, still with vertical attitude, had formed.

"The top of the deposit is in most places 1 to 3 feet below the surface of the bed rock, but this in turn is covered with an overburden of talus, 10 to 20 feet thick. The age of the deposit is definitely "post-faulting" which means since the middle of Cenozoic time, but deposition might have been any time from then up to the present. Similar deposits of travertine are forming today in many parts of the region where there are permanent or semipermanent flows of water." (end of quote)

From this statement it is clear that dead Arthropods washed into such flows of water or accidentally drowned in them could

easily have been engulfed in depositing calcite. It is therefore rather surprising that fossil specimens have not previously been found in such deposits. A further search may bring to light much new material nearly related to the present fauna and yet distinct from it.

When the first pen base was received it was 19 mm. thick, polished on the surface, brown in color and translucent in strong artificial light. The fossil was near the surface and plainly visible presenting its ventral surface to the observer. Through the courtesy of Doctor Dunbar, Director of Peabody Museum, the sectioning was done for me by an expert of the Museum. Finally I myself polished down the piece to a thickness of 1 mm. and mounted it on a slide in clarite under coverglass, making examination of both sides possible in reflected as well as in transmitted light. Unfortunately it became immediately apparent that only the ventral body wall is present and that the segmentation of the abdomen is not visible from either side. The latter character is clear in the paratype which happens to be visible only from the ventral side. But although the carapace of the fossil under consideration is missing, the arrangement of the coxae and the structure of the appendages leave no doubt as to its affiliation. It belongs in the same group with the recent Tartarida (Schizopeltidia) until now considered to be a Suborder of the Order Pedipalpi. In another paper I give the reasons why the Suborder should be raised to the status of an Order and why its name is better changed to Schizomida. This is the first case of a fossil belonging to the Order Schizomida that came to light. Hitherto only representatives of Uropygi, Holopeltidia, and Amblypygi of the old Order Pedipalpi have been described as fossils, all from the Paleozoic.

Although represented in various parts of the globe by recent species, the Order Schizomida is a very small one and consists of a single Family Schizomidae with three Genera, *Schizomus*, *Trithyreus* and *Stenochrus*, comprising not quite three dozen species. All are small, terrestrial and more or less alike in appearance. All have nearly the same structure including the presence of three tarsal joints on the second, third and fourth pair of legs. The new fossil species has five tarsal joints on the second leg and four on the third and fourth leg. Such a difference clearly is of fundamental importance as otherwise a variation in the number of tarsal joints would

be found in recent species. The difference seems to me to be of familial value and the new fossil Family Calcitronidae may be distinguished from the recent Family Schizomidae by the number of tarsal joints. The new Genus *Calcitro* shows in addition to the familial characters its generic character in the shape of the fourth trochanter which is slightly longer than the corresponding coxa. The name is a Latin noun meaning a kicker. In Recent Schizomids the fourth femora are greatly distended and they are somewhat distended in the fossil species. The name was chosen by me, however, because its sound reminds one of calcite in which the fossil was found, even though the two words have nothing in common with each other.

Order Schizomida, new name

Family Calcitronidae, new

Genus Calcitro, new

Calcitro fisheri, new fossil species from the late Cenozoic of Arizona. Holotype, paratype and three other specimens, all found in onyx marble from the Bonner Quarry near Ashfork.

DESCRIPTION OF HOLOTYPE.

As shown in the accompanying photograph the specimen lies with its ventral side up and is incomplete. The following parts are missing. On the left side of the animal the pedipalp with exception of its coxa; patella, tibia and tarsus of the first leg (the patella of the first leg is always permanently fused with the tibia and not distinguishable as such); the metatarsus of the first leg is displaced forward out of its normal position; metatarsus and tarsus of the second leg; the third leg is complete, but its metatarsus and tarsus are broken off and displaced forward; the fourth leg is also complete, but the proximal portion of the tarsus is so transparent that it may be recognized only by its hairs which remain clearly visible, while the terminal joint with the claws is broken off and displaced backward. On the right side of the animal all appendages are complete, only the femur and tibia of the first leg are missing and the fourth leg is broken between the patella and tibia and the latter with the metatarsus and tarsus are displaced backward. The carapace is missing. The abdomen is so poorly preserved that segmentation cannot be made out. The tail is displaced to one side over the end of the abdomen and is not clearly visible.

Total length from end of pedipalpal coxae to visible end of

abdomen 4.4 mm. Abdomen 2.9 mm. long, 1.6 mm. wide. Probable order of legs 1432

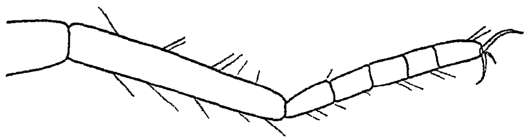
	Coxa	Trochanter	Femur	Patella	Tibia	Metatarsus	Tarsus	Total
I	0 42	0.31	1.09	missing	1 85	0.94	0.99	5 10
II	0.54	0.27	1.00	0.40	0.73	0 52	0.48	3.94
III	0 40	0 35	1.00	0 40	0.73	0 60	0.57	4 05
IV	0.40	0 46	1.13	0.46	1 11	0.84	0.65	5 05

The chelicerae are not visible. The structure of the pedipalpi and the arrangement of the coxae are typical of the Order (Text Fig. 5). The coxae of the pedipalpi are contiguous along their entire length and their mobility is therefore presumably very limited. The coxae of the first pair of legs are cylindrical, relatively thin and wide apart. The coxae of the second pair of legs are elongated cone shaped with the apices almost but not quite meeting in the median plane and the usual thorn at their anterior end present, but rather small. There is no indication of a sternite in the space in front of the second coxae although it is most likely that such a sternite typical of Recent species, must have existed and simply became invisible in the process of fossilization. The coxae of the third pair of legs are only little wider at their apical end, and are sub-contiguous at their base. The coxae of the fourth pair are cylindrical and meet in the median plane. All trochanters are single jointed. Those of the pedipalpi have a distinct anterior apophysis, those of the fourth pair of legs are cylindrical and slightly longer than the coxae.

The pedipalp becomes gradually more slender toward the end. Of interest is the fact that its patella is as long as the tibia and cylindrical, whereas in the legs, except the first, the patella is much shorter and of a shape characteristic for whip-scorpions and spiders. As already stated the patella is permanently fused with the tibia in the first leg. The terminal joint of the pedipalp is more or less cone-shaped and ends in a slender, long and smooth, slightly curved claw. A spine is present on the ventral edge of the joint as shown in Text Fig. 5 A few hairs may be seen on the trochanter and on the terminal joint.

The femur of the first pair of legs is slender, cylindrical. But the femora of the second, third and fourth pair are distinctly distended in the middle. However, the fourth femur is not nearly as much distended as in recent species. The tibia and metatarsus present no peculiarities, but the tarsus does.

1



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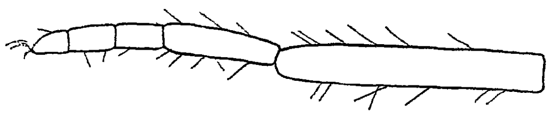

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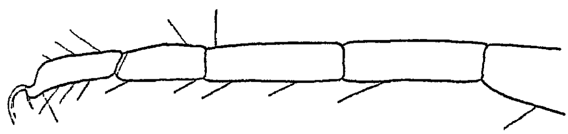

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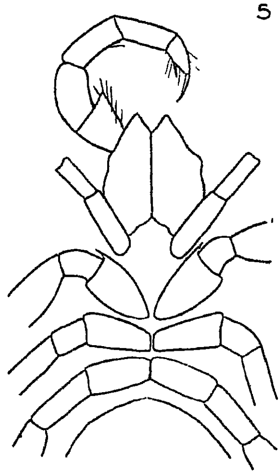
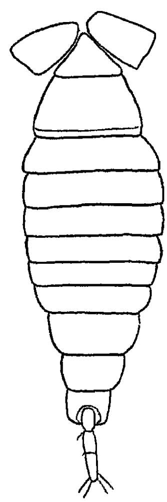




Line drawings. All made with the aid of a camera lucida. Figs 1-4 are magnified 60 diameters, Figs. 5 and 6—45 diameters, Figs 7 and 8—60 diameters

Figs. 1 to 5 are drawn from the holotype. The legs numbered in their proper sequence.

Fig 6 represents the ventral aspect of the abdomen in the paratype.

The number of its joints in the first pair of legs (Text Fig. 1) is the normal one for the Order, namely 7, the first joint being the longest, the second as long as the seventh which has no claw. The tarsus of the second leg (Text Fig. 2) is five-jointed, and has the usual three claws at its end. The upper claws are long, smooth, curved and slender, the third claw is much shorter, smooth, and fine. The tarsus of the third pair of legs is four jointed (Text Fig. 3), the first joint by far the longest, and the entire tarsus but little shorter than the metatarsus. The three claws are of the same type as those of the second leg, but not as well visible owing to the position of the leg. The tarsus of the fourth pair of legs is distinctly shorter than the metatarsus, but considerably longer than the tarsi of the second and third legs (Text Fig. 4). Its first and second joints are of equal length and considerably longer than the third and fourth joints. The shape of the fourth joint suggests that the claws are born on an onychium which seems to be here better developed than on the third and second tarsi. The claws are of the same type and are well visible in profile. Hair is present on all legs. It is short and of the simple kind.

The abdomen is undoubtedly distended, presumably by pressure, possibly by the presence of eggs. In reflected light it appears to be uniformly white, but in transmitted light one can see in the middle some rounded bodies which are much darker than the surrounding portions. No traces of segmentation can be seen either in reflected or in transmitted light. The tail is barely visible, somewhat displaced to one side, superimposed over the end of the abdomen.

The holotype bears the catalogue number Y.P.M. 17380.

DESCRIPTION OF PARATYPE.

As already stated the paratype is in the second pen base of onyx-marble sent to me for examination. The pen base is rectangular, three quarters of an inch thick, $6\frac{3}{4} \times 4\frac{1}{2}$ inches, with a circular excavation of $1\frac{5}{8}$ of an inch in diameter for the reception of an ink-well in the median line of the block not far from its back. The fossil, well visible to the naked eye, is close to the surface and with its venter up, as shown in the photograph. In some respects it is better preserved than the type, but unfortunately can be studied only by reflected light.

The chelicerae are not visible. The left pedipalp is complete, the right one broken in two places and displaced. Both legs of the first pair are broken. The two end pieces consisting of the metatarsi and tarsi are displaced forward and are parallel to each other. Except for this displacement of its anterior portion the left first leg is complete, but of the right first leg the tibia is missing. The second left and the third and fourth legs of both sides are complete. The second right leg is broken at the end of the tibia and two of the pieces lie separately. The coxae are poorly visible. The abdomen is complete and its segmentation plainly visible in reflected rays striking the segmentation lines at right angles. As shown in Text Fig. 6, 11 sternites are visible. The first sternite is triangular and occupies the space between the fourth coxae. The second sternite represents undoubtedly the fused second and third abdominal somites as is usual in Recent Schizomida. There is even something like an indication of its composite nature in the presence of a thin line in front of the posterior intersegmental line. The last segment is almost as long as wide and shows a circular depression in which the tail is inserted. The latter seems to be three-jointed, although on account of its position slightly turned up at the end and because of some imperfection of the rock in that place, the number of segments is difficult to make out with certainty. A few hairs are plainly visible on the tail, but neither the genital opening nor any respiratory openings can be seen in the places on the abdomen where they are found in recent species. My experience taught me that these structures are extremely rarely visible in fossil arachnids.

The coxae are not as plainly visible as in the type. Nevertheless one can make out with certainty that their disposition is the same and the second coxae show the apical spur quite plainly. The sternum is not visible. Exact measurements are somewhat difficult and therefore given here to the first decimal only. Total length from the anterior end of the pedipalpal coxae to posterior end of tail 4.0 mm. Abdomen to base of tail 2.5 mm. long. Order of legs 1432.

	Coxa+Troch.	Femur	Pat.+Tibia	Metatarsus	Tarsus	Total
I	0 6	1 2	1.0	1 0	1.0	4 8
II	0 6	1 0	1.0	0.5	0.3	3 4
III	0 6	1.2	1 0	0.6	0.6	4 0
IV	0.6	1.2	1 4	0.8	0.7	4.6

In the same pen base with the paratype three other fossils are present, which I refer to the same species. All three are somewhat smaller and poorly preserved. The one which lies about 25 mm. from the paratype at a place corresponding to 1 h. on a clock dial is better visible than the other two and shows at the end of the abdomen a three-jointed tail.

In the same pen base with the type and now, like the latter, cut out, polished and mounted on separate slides, were two fossil appendages. The first of these shown in Text Fig. 7 seems to be four-jointed, the last two joints forming a chela.

7.

8

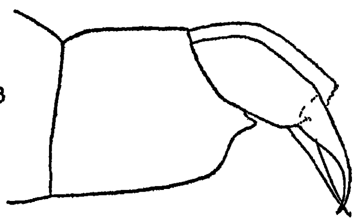
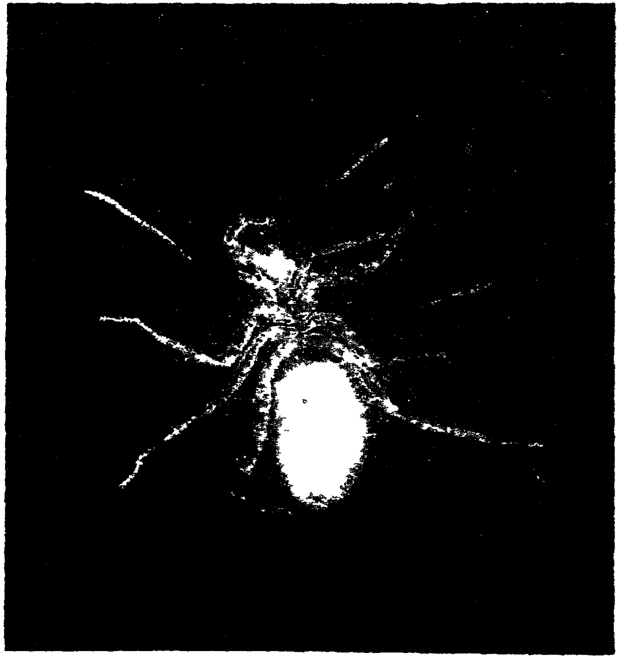


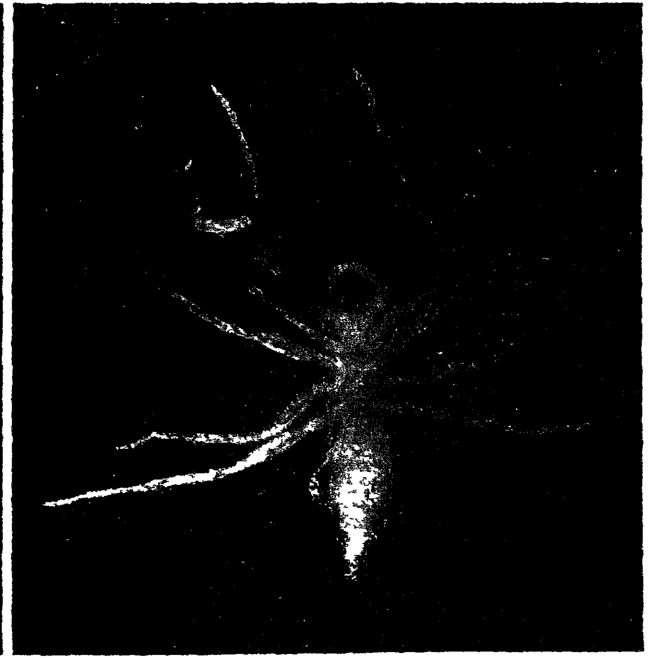
Fig. 7. A chelate appendage of an undetermined fossil on the same pen base with the holotype, magnified 60 times.

Fig. 8. Another chelate appendage of a fossil found in the same pen base with the holotype.

Immediately behind the basal joint two other very thin and long appendages recognizable as such by the presence of hair are visible. One of these is bent upward, the other extends forward and crosses the chela. They are omitted from the drawing because no detail may be made out. I am at a loss to suggest even the Class of Arthropods to which this remnant of a fossil belongs.

The appendage No. 2 represented in Text Fig. 8 is larger than the one shown in Text Fig. 7 and relatively stouter. As in the latter the movable finger which is the more slender one is, as the drawing shows, the ventral one. The segment posterior to the hand does not look like a portion of the appendage which I am inclined to consider as being two-jointed. That segment must be therefore representing either the carapace or a capit-





TYPE CALCITRO FISHERI PARATYPE

Photographs *Calcitro fisheri*, n g., n sp Holotype on the left, paratype on the right, both at a magnification of 10 diameters Both photographs were made in artificial reflected light without rayfilter, on an orthochromatic plate.

ulum as found in mites. The appendage is a chelicera, but cannot be one of a Schizomid, because in Schizomida the movable finger is always the dorsal one. Several long, slender and hairy appendages not shown in the drawing are visible in various positions, but so disrupted and so poorly preserved that nothing definite can be said about them. Behind the segment mentioned above another piece is visible. It may be the body proper of the fossil badly torn and pressed out of shape. The fossil may be a mite.

The paratype bears the catalogue number Y.P.M. 17381.

References.

For the benefit of those not familiar with the recent Schizomida a few references are given here.

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5. Kästner, Alfred: 1932, Pedipalpi, in Kükenthal's Hanbuch der Zoologie Vol. III, Part 2.
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8. Thorell, T.: 1888, Pedipalpi e Scorpioni dell' Archipelago malesi etc. Ann. Mus. Genova, Vol. XXVI, pp. 327-428.

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GROUND MORAINE: A TERM IN GLACIOLOGY.

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ABSTRACT. Since the introduction of the term ground moraine by Louis Agassiz, its significance has been altered so that what was originally intended as the name of subglacial till is now being extended to include the upper till, and even the assorted drift.

BEING products of living thought, concepts are mutable; and the words employed to symbolize them, being fixed, are frequently unable to express and convey this mutability. In addition to what may be regarded as the normal (because unavoidable) discrepancies between concepts and their symbolic representations, there are discrepancies caused by inattention, persistent abuse, and by carelessness. From the latter kind of mischance the terminology of a branch of science is supposedly protected by the watchfulness of its devotees, but of the terms used in describing glacial phenomena some have slipped whatever moorings they may have had; and among them none has drifted farther than the term ground moraine.

There was a time when the word moraine carried no implication of association with a glacier. There was, to be sure, more or less moraine at the foot of an ice slope, but there was plenty of moraine elsewhere: it was the stuff in which you planted your turnip seed and buried your dead; and the gardeners and grave diggers were not interested in geomorphology. The Old Savoy meaning appears to have been "loose, earthy material"; and, since nouns denoting material are frequently transferred to objects composed wholly or predominantly of that material, it is probable that all welts on the hillsides due to talus creep or to landslides (as well also the débris that slid onto the margins of glaciers) came to be known as moraines. But that this cognate concept took no account of any theory of origin is evident from the fact that those embankments which lay upon and crossed the valley-bottoms were also called moraines.

It was these embankments of moraine which brought about the intimate and almost exclusive association of the word with glaciers. After the publication of John Playfair's *Illustra-*

tions of the Huttonian Theory (London, 1802),[1] some of the embankments in the Swiss valleys came to be recognized as indices of the former positions of an ice-foot; and in many parts of Europe the term was otherwise meaningless.

When the interest of Louis Agassiz had been enlisted in the problem of a climate that anciently had favored greater extension of the Alpine ice-rivers, he and his associates carried their investigations to the point where invention of new terms was inevitable. Among them was *ground moraine*. Under the glaciers and over the floors from above which (it was inferred) they had recently melted off, there were found patches of exceedingly tough "mud" enclosing striated stones, and evidently making up part of the surface over and upon which the ice moved. For this discontinuous layer, since it was neither "loose, earthy-material" nor an aggregate thereof built as the ice melted, the designation was not a particularly happy one. The most that can be said for it is that it then implied some sort of a deposit associated with a glacier.

When seeking in England for evidences to support his hypothesis of planetary refrigeration, Agassiz was on the lookout for four things: "sheep-rocks," moraines (meaning the end moraines of local glaciers), scratches on the bed rock and exposures of that basement material, "stones impacted in mud." At that time, what (later) came to be called the upper till was being interpreted as a deposit of marine origin, "the northern drift"; and theory had been elaborated to explain much of its detail. Whatever opinion Agassiz may have held concerning this "drift," it is certain that he would have met with little success in urging any other explanation for it. His "ground moraine," however, was as characteristically glacial as the striae and sheep-rocks, and this eventually came to be known as the lower till.

The distinction between upper and lower tills appears to have been made (and to have been understood in the original sense) by all who used the terms until the time when a glacial origin was first claimed for the "drift" (the upper till and the boulders). This attack upon a long established theory soon had geologists divided into opposing camps: the Glacialists

[1] Playfair had written: "for the removing of large masses of rock the most powerful engines without doubt which nature employs are the glaciers Before the valleys were cut out in the form they now are, . . huge fragments of rock may have been carried to a great distance . . ."

and the Diluvialists. The controversy that followed is as yet unsettled: the Diluvial-minded now have to keep the ocean off from the mountain tops, but they are still disputing a strip of variable width along the sea coasts. (That, however, is another story.) What is more important to note is that, in the heat of debate, the Glacialists became a bit careless with terms. There is so little (comparatively) true ground moraine exposed to argue about, and so much of the dross dropped from the ice as it melted (but not heaped up in end moraines) that the "diluvion" overlying the "stones impacted in mud" needed a name. In some writings it was called the upper till; but in Sweden both tills, so it would seem, were sometimes lumped together under one name, ground moraine.

In 1876, Prof. Otto Torell of that country came to America and propagated this terminology as follows: "all the material deposited beneath the advancing ice, *together with that deposited from the base as an irregular sheet during the melting,* constitutes the ground moraine."[2] And, since (in this country) little attention had then been given to any division of the till into upper and lower, Torell's classification was generally adopted here, and the good term ground moraine began to drag its anchor.

Let us, at this point, return to a consideration of the matter of concepts and their symbolic representation by words. There was once a culinary concoction known as mince-pie which derived the qualifying part of its name from the minced meat used in its construction. The thing symbolized underwent change but the symbol remained unaltered until, today, a few raisins and bits of apple baked between crusts is called mince-pie. Similarly (1) to the "stones-impacted-in-mud" of Louis Agassiz was added the overlying dross from melting of the ice with both subsumed under one name; then: (2) because the added element is at the surface so much more abundant, it was allowed to absorb almost all of the meaning in the term which had been exclusively the name of the now slighted lower member. In the instance of mince-pie: it is necessary to remember only that there is no institution charged with the duty of guarding every-day speech from one generation to the next. In the case of ground moraine: one wonders how

[2] Torell, O.· 1877, On the Glacial Phenomena of North America, Amer. Jour. Sci., 3rd Sers., 13, 76-79.

and why the change was brought about: doubtless Torell was merely the carrier of a usage already established.

But, though the beginnings may be obscure, there should be little difficulty encountered in tracing the perpetuation of this abuse in the American geological literature. An elaborate documentation is hardly called for; and the four citations that follow will, it is thought, suffice to cover the sixty-odd year interval up to the present day.

FIRST: The explicit statement of George H. Stone made in a paper read before the Boston Society of Natural History on March 3d, 1880[3]: "Ever since the publication of the views of Prof. Otto Torell as to the drift of eastern North America . . . , the writer has regarded the classification proposed . . . as substantially representing the succession of glacial deposits in Maine." Stone did not, however, accept Torell's addition to ground moraine, namely: "*together with that deposited from the base . . . during the melting*": he distinguishes "the lower till, supposed to be the ground moraine of the continental glacier" from the "upper till, supposed to consist of the morainal detritus which was *in* the ice, and above the land surface."[4]

The same terminology was employed by Hitchcock and Upham in the Geology of New Hampshire (1878).

SECOND: Discussion of the two tills in any one of the several articles written by T. C. Chamberlin to set forth his "Proposed Genetic Classification of Pleistocene Glacial Formations." The text here followed appeared in 1894.[5] Torell's lumping of the tills is considered likely to be misleading and new names are therefore proposed for the tills.

Of the "formations produced by the direct action of Pleistocene glaciers" distinction is made between those "that gathered at the bottom of the glaciers" and those "derived from material borne on the glaciers and within them and deposited at their margins, or let directly down by their melting, when stagnant." "Of deposits originating under the ice" the recognition of subclasses is urged: drumlins, tumuli, billows, hills, ridges, and other modifications of the ground moraine each of which is raised to the rank of a concept having equal standing

[3] Stone, George H.: 1880, The Kames of Maine Proceedings **20**: 430-469.
[4] Ibid, 433-434.
[5] Chamberlin; 1894, Jour. Geol. **2**: 517-538

with "sheets of subglacial till" which are demoted to the status: "one form of ground moraines." So now, for T. C. Chamberlin at least, every detail of the original ground moraine has become *a* ground moraine, each one correlative with the other details. It is hardly a matter for wonder that in his discussion he makes use of the old term but twice out of thirty occasions, its place being taken by "drift accumulations" (four times) and by "subglacial till" (twenty-four times).

For the term "upper till" this author proposed "englacial or superglacial till," the alleged reason for the new words being that the old term had been "also used to designate a reduplication of the subglacial till sheet." Whatever may have been the justification, terminology was enriched(?), and science was given a few more tools to carry in order that it might advance more rapidly and smoothly. "Ground moraine" was snowed under, and might have been expected to disappear before the end of the century.

Nevertheless, maps continued to appear showing areas which bore the color-symbol for "till"; and the reason therefore is not far to seek. An areal map exhibits what has been found by the surveyor; and that is *not* superglacial or englacial or subglacial till, but only what he interprets as *having been* super-, en-, or sub-, when the ice was here. Melting of any broad expanse of the glacier's surface, whether the glacier is in motion or stagnant, gradually converts englacial till into superglacial till; and, when the ice is finally gone, all that can be discerned is a sheet of merely till. (In many regions it is practically impossible to identify weathered ground moraine and to distinguish it from upper till.)

The succeeding references are to publications that typify a more recent trend: the resurrection of Agassiz's old term ground moraine and its use *as a substitute for "upper till,"* a use which is neither warranted nor, in the writer's opinion, wholesome; it is a return to that abuse in the terminology of Otto Torell (1876) noted above, an abuse which, whatever may have been its persistence in Europe, had not, previously, found favor with American geologists.

THIRD: Plate 2 accompanying U. S. Geological Survey Bulletin No. 839, being a map showing surficial geology[6] based on field work carried on at intervals from 1892 to 1921. Till

[6] La Forge, Laurence: 1932, Geology of the Boston Area, Mass.

is not recognized as one of the glacial aggregates appearing within the limits of the map though there is much of it; and areas known to the writer to be till are given the color pattern and letter symbol which, so the legend proclaims, indicate "ground moraine." Professor LaForge knew what he was mapping and cannot be held responsible for this reversion to Torell's nomenclature; why should the United States Geological Survey abandon Chamberlin's term and adopt one formerly rejected not only here but also in Sweden?

FOURTH: A study of the glacial features of a part of western New York[7] in which the topography of what is called the Binghamton drift sheet is described, in part, as follows: "The Binghamton drift sheet exhibits a considerable variety of topographic forms which may, for simplicity, be grouped into six types: . . . (1) . . . ; (2) Ground moraine blankets the interfluve uplands of the region covered by this drift sheet. It consists predominantly of till, though a few small kames and kame fields have been noted" (pp. 1157-8). So here we have "ground moraine" used to include not only the tills, but also some at least of the kames and kame fields. Confusion worse confounded! It is indeed possible that some of the kame forms will turn out to be modifications of the upper till and, as such, not to be classed with the assorted drift forms; but this also is another story.

[7] MacClintock, Paul, and Apfel, Earl T.: 1944, Correlation of the Drifts of the Salamanca Re-entrant, New York Bul. Geol. Soc Am, 55: 1143-1164

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GASTROLITHS FROM MINNESOTA.*

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ABSTRACT. The Dakota formation is represented by conglomerates, sandstones and shales extending eastward into southern Minnesota. Some portions of these contain smooth and highly polished pebbles that are believed to be gastroliths. They seem to suggest the presence of dinosaurs on this part of the continent during the Cretaceous.

INTRODUCTION.

DURING the late Paleozoic and early Mesozoic much or all of Minnesota appears to have been a land area that was undergoing erosion, deep weathering, or extensive leaching and solution of its limestone areas. The deeply weathered Pre-Cambrian, and the old residual iron deposits now found on top of the Paleozoics, may have been formed largely during that long interval of emergence from the late Paleozoic and early Mesozoic seas With the beginning of the Cretaceous, however, sedimentation began over parts of what is now the state and a more detailed recording of major events was restored once more. During this time the land areas probably were suited to terrestrial inhabitants and undoubtedly such forms roamed over the Minnesota region.

THE DAKOTA FORMATION.

Sandstones and shales representing the Dakota formation extend into Minnesota and have been identified by their well preserved flora. A meager molluscan fauna also suggests the same age for these deposits. Eastward the Dakota wedges out against older rocks of the central and eastern parts of the state. At New Ulm the formation is chiefly a sandstone but it contains conglomerates, shales and even thin streaks of lignite. Still farther to the east the conglomerates become somewhat coarser and constitute a larger proportion of the formation. In Olmsted, Mower and Fillmore counties some of the pebbles are quite large and many of them are chunks of rock of cobblestone size or larger. Most of these latter are flint or chert nodules that have weathered out of the underlying rocks, hence have not been carried very far. In fact

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many of them are not even marked by erosion and their surfaces still show well preserved fossils of the formations (chiefly Devonian) from which they were derived.

THE OSTRANDER MEMBER.

The old gravels, lying below the loess and the drift of the southeastern region, are yellow to brown from the great quantity of iron oxide associated with them and the thin film of the same oxide that partly covers the pebbles, but the pebbles themselves are white to pink quartz with flint and chert running a close third. Most of this iron within the conglomerate and associated with the pebbles or forming the cement, may have been derived from the residual iron of the old weathered surface below. In the southeastern region, particularly in Mower and Fillmore counties, these poorly cemented conglomerates or gravels take on much importance and have been widely used for surfacing secondary roads. Gravel pits in the formation are numerous and these beds have been named the Ostrander member[1] of the Dakota formation, from the pits near the town of that name in southern Fillmore county. These yellow conglomerates or gravels should not be confused with the yellow glacial gravels, carrying numerous igneous pebbles, occurring in the same region and that have materials in part derived from the Ostrander.

GASTROLITHS.

The pebbles in the gravels or conglomerates of the Ostrander member are well worn and some are smoothed or even polished by water action. Scattered among the common pebbles of the gravels, however, are larger ones, mostly chert, that are highly polished and at once suggest a somewhat different origin from that of the more usual ones. These highly polished pebbles are angular to subangular and rounded forms weighing up to four or more ounces. The polish is uniform over the whole surface and tends to extend into the pitted areas as well. The origin of these larger and highly polished pebbles is a problem quite aside from that of the residual chunks mentioned, or the origin of the water-worn quartz and flint pebbles that constitute the major part of the conglomerate. In most gravel pits opened

[1] Stauffer, Clinton R., and Thiel, George A.: 1941, Minnesota Geological Survey, Bull. 29, 103.

in this poorly cemented Ostrander member these objects are not very common but in the pits and road cuts on the low ridge south of Bear Creek, near Racine, Mower county, they are fairly abundant. At least it is a place where one might be reasonably sure to find a few. Careful search, however, will reveal them in nearly every pit where the Ostrander gravels are actively worked.

The transportation or agitation of small pebbles and sand grains in water may produce smooth surfaces, which, in the case of sand and small quartz pebbles, may approach a polish. That appears to be the cause of the smoothness of many of the ordinary pebbles of the Ostrander but it does not seem to apply to the high polish of the larger ones. The idea of dust polishing suggested itself as a possible explanation of the smooth surfaces of these pebbles. Ventrifacts are often well polished on the exposed surfaces and since it is easily shown that under certain conditions the pebble frequently may be turned completely over, such polish may cover the entire surface. Wind wear and polish may produce the characteristic unikanter or einkanter and the dreikanter shapes so well known in dry or arid regions. The polished surfaces of such ventrifacts are likely to be "distinguished by their well-smoothed, fine matte surface and shallow irregular pitting,"[2] but none of these attributes seem to apply to the smoothed and polished Ostrander pebbles of southeastern Minnesota.

The first of these pebbles was found by Mrs. Stauffer while we were working along a hillside adjacent to Highway No. 63 some four or five miles southwest of Lake City, Wabasha county, during the summer of 1937. Later they were found from Goodhue and Bellechester on the north to Etna and Cherry Grove on the south and in nearly every exposure of the Ostrander gravels. Always they are the hard flint, or quartz pebbles with an occasional stray that may be a banded jasper. Many of them may be located stratigraphically by their petrographic composition. Thus the first one found, or the one from a point near Lake City, is a piece of oölitic chert from the Shakopee formation. It is very highly polished and beautifully preserved. Others carry Devonian fossils and their horizon is thus determined.

[2] Smith, H. T. U.: 1940, State Geological Survey of Kansas, Bull. 34, pl. 10.

See also Baker, A. A., Dane, C. H., and Reeside Jr., J. B: 1936, United States Geological Survey, Professional Paper 183, 6, pls. 13 and 14

The suggestion that these highly polished pebbles are gastroliths or gizzard stones of dinosaurs was one of the first conceived. A representative selection of the polished pebbles from a dozen or more Minnesota localities was compared with a handfull of gastroliths from the Trinity beds of Texas and another from the Morrison beds of Wyoming and still another handfull from the Morrison beds of Utah with most interesting results (Plates 1 and 2). Every feature shown by the pebbles from the plains and mountain states are present in the specimens from the Ostrander beds of Minnesota. In fact when they were placed side by side it was impossible to distinguish any of them from the others. A dozen or more of the Ostrander pebbles were taken to a recent meeting and were exhibited to various members of the Paleontological Society. Everybody who saw them pronounced them gastroliths, although there was some hesitancy when told the specimens came from Minnesota. The fact is no finer collection of gastroliths can be made anywhere than in southeastern Minnesota. There is no intention to attack or discuss the interpretation of gastroliths as the gizzard stones of ancient reptiles. The point is that here on the prairie in the Mississippi Valley, almost adjacent to the river, there are pebbles in an outer edge member of the Dakota formation that answer to the description of gastroliths and match those from widely separated regions. They are probably as truly gizzard stones as any found anywhere in the United States.

To date no skeletal remains of dinosaurs have been found in the state, but the life conditions that are suggested by the Ostrander deposits are quite similar to those that must have prevailed farther to the west during the Morrison, and the land area now Minnesota doubtless was then a suitable habitat for the dinosaur and hence it probably was inhabited by the reptilian hordes which we know were then roaming other parts of the continent. The Cretaceous sea that spread over other parts of the state a little later (Benton) had its marine reptiles and they have scattered their remains over the Mesabi district. Probably then too the adjacent shores teemed with reptilian life, although no certain evidence has been identified. Unfortunately in the north the glaciers did a rather thorough job of erasing the Mesozoic, and the drift has all but completed the task of burying the remnants too deeply for easy access.

CONCLUSION.

The highly polished pebbles of Dakota age in southeastern Minnesota are probably gastroliths. If gastroliths are gizzard stones and mean the presence of dinosaurs, it seems certain that Minnesota was a part of their range during the Ostrander stage at least. Hence one may expect that sooner or later reptilian remains will be found in the remnants of the Dakota formation in Minnesota.

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MINNEAPOLIS, MINNESOTA

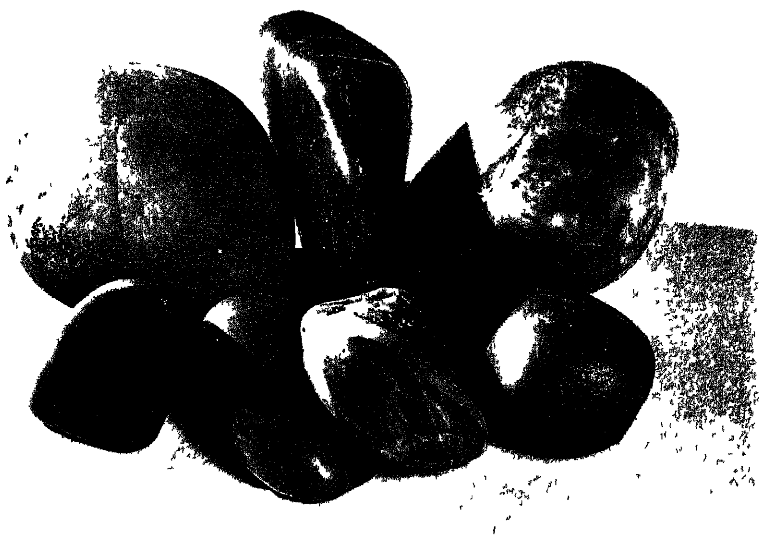


Fig 1 or upper (½ natural size).
Gastroliths from the Morrison beds at Kane, Big Horn Basin, Wyoming
Fig 2 (½ natural size)
Gastroliths from the Trinity sand at Cross Cut, near Cross Plains, Texas

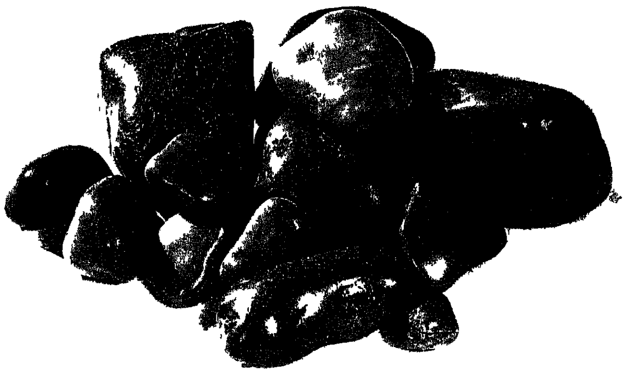


Fig 1 or upper (½ natural size)
Gastroliths from the Morrison beds, Cleveland, Utah
Fig. 2 (½ natural size).
Gastroliths from the Ostrander beds along Bear Creek, two miles south of Racine, Mower County, Minnesota

FOUR NEW GENERA OF CAMERATE CRINOIDS FROM THE DEVONIAN.

EDWIN KIRK.[1]

ABSTRACT Two genera, *Pithocrinus* and *Cadiscocrinus*, are proposed with new American species as types *Pithocrinus* is also represented in the Devonian of France and Spain. *Ambicocrinus* and *Griphocrinus* are proposed for the reception of described species. A species from the Devonian of France is referred to *Griphocrinus*

PITHOCRINUS, new genus.

Genotype.—*Pithocrinus cooperi*, new species.

Theca. Composed of heavy plates forming a competent structure. Above average size for batocrinoids of this time, excepting such genera as *Megistocrinus* and *Gennaeocrinus*. Dorsal cup cupuliform. Tegmen convex to moderately elevated, composed of many relatively small plates. In *P. cooperi* some of the plates of the tegmen are relatively large and bear subspinous processes. Anal tube stout, subcentral. Plates of the dorsal cup convex to tumid or tuberculate.

BB. Three. Relatively small, subequal. Commonly produced into a distinct flaring tripartite petaloid rim.

Radial series. *RR* large, followed by two *IBrr*. In four-rami rays there are one or two *IIBrr*. In these rays there are usually two *IIIBr* incorporated in the cup. When but two rami are borne, there are usually three *IIBrr* incorporated in the cup.

Interbrachial series. In the *post IR* the anal is about equal in size to the *RR*. It supports the customary three batocrinoid plates. These are large, and at this level the *post IR* has its greatest width. Distad the *post IR* narrows and is composed of smaller plates, somewhat irregularly arranged.

In the other interradii the first interbrachial is large, supporting two smaller plates. Distad the interradius narrows rapidly. In the two-rami rays there are two small *iIIBrr* in linear series. In the four-rami rays there are one or two *iIIBrr* separating the two pairs of arms.

Arms. The arms are unknown, but were exceptionally stout for a crinoid of this size. In two species there are four rami

[1] Published with the permission of the Director, Geological Survey, United States Department of the Interior.

to each ray. In the other forms there are four rami in the *r* and *l post* and *ant RR* and two in the *r* and *l ant RR*. In the *l post R* of the holotype of *P. waliszewskii* the usual four is reduced to three by suppression of one-half of one division in the secundibrach series.

Stratigraphic and geographic distribution.—*Pithocrinus* is known only in the Middle Devonian of Michigan and Spain.

Relationships.—Lacking the arms, one has difficulty placing *Pithocrinus*. Probably if the arms were preserved one would have the same trouble. Superficially the genus resembles a *Megistocrinus* with an exsert base. The stout, subcentral anal tube, the smaller number of *IIBrr*, and the lack of incorporation of the higher orders of brachials clearly differentiate *Pithocrinus* from *Megistocrinus*. For want of better placement and until more is known of the batocrinoid stocks in the Silurian and Devonian one could place the genus in the Periechocrinidae.

Remarks.—In the collections of the United States National Museum are two specimens from the Traverse group of Michigan that are referable to *Pithocrinus*. They may be conspecific, but owing to their poor preservation it has not seemed desirable to describe them. They show an interesting variant in tegminal structure from that shown by *P. cooperi* and more nearly agree with the Spanish forms. One of the specimens is from the upper Alpena in the Michigan Alkali Quarry near Alpena, Michigan. The specimen is crushed vertically, is partially exfoliated, and the remaining surface is partially covered by encrusting bryozoans. The species is larger than *P. cooperi*. The height is estimated as at least 32 millimeters and the average diameter, 40 millimeters. The tegmen is arched, but relatively low, with well-defined depressions in the interambulacral areas. The tegmen is composed of many small plates. None of these is tuberculate. There are four rami in the *r* and *l post* and *ant RR*. There are two rami in the *r* and *l ant RR*. There are well defined gaps between the arm-groups, that in the posterior interradius not being appreciably wider than the others. The other specimen is from the Traverse near Petoskey, Michigan. It is a smaller theca in a fair state of preservation other than being badly crushed.

In the Springer collection there is a well-preserved theca that apparently represents a new species of *Pithocrinus*. This specimen is from the Devonian of Colle, Spain. The dorsal cup is very like that of *P. cooperi* in shape. The tegmen is

highly arched. As in *P. intrastigmatus* there are four rami in each of the rays. All the plates of the dorsal cup are tubercular, and in addition there is an obscure granular to vermicular ornamentation. Some of the plates of the tegmen bear small spinous processes.

PITHOCRINUS COOPERI, new species.

Plate 1, Figs. 4-7.

There are two specimens of this species. The larger specimen, the holotype, is a well-preserved, uncrushed theca. The smaller specimen is equally well-preserved, but a portion of the dorsal cup and tegmen constituting about one-fourth the bulk of the specimen is broken off. Both specimens are partially silicified.

The holotype has a height to the base of the anal tube of 39 millimeters and an average diameter of about 35 millimeters. The height of the dorsal cup is approximately 22 millimeters. The shape of the cup and tegmen may readily be seen in the figure. The anal tube is broken off, but was stout. It is subcentral in position. The plates of the theca are thick. In the smaller specimen the plates of the dorsal cup are tumid. In the older specimen the plates of the dorsal cup have a marked convexity. In the case of the larger plates each has a well-defined central protuberance. In both specimens many of the plates of the tegmen are produced into short, heavy processes. These processes are naturally more strongly developed in the larger individual.

The basals stand out sharply and in basal view have a petaloid appearance. The primibrachs have the usual sequence. In the *r* and *l post RR* the series are thrown out of vertical alignment by crowding of the plates of the posterior interradius.

In the *r* and *l ant RR* there are two large fixed *IIBrr* in each half of the ray. In these rays but two free rami are borne. In the other three rays there is a single *IIBr* in each half of the ray, which is axillary. Each axillary supports two *IIIBrr*, the first being larger than the second. The *r* and *l post* and *ant RR* thus bear four free rami. In the younger specimen there is close spacing of the arm bases within a ray, but a clearly defined gap as between the arm groups of adjacent rays. The gap in the posterior interradius is somewhat

wider than that between the arm groups of the other rays. In the older specimen the gaps have closed, and there is practically no difference in spacing as between the arm bases within the ray groups and those of contiguous rays. In this specimen in the *post IR* a small portion of the periphery is broken off, but it would appear here that there is a noticeable gap. The interradial areas are relatively small, with the exception of the posterior. In the *post IR* the anal is followed by the customary three plates of the batocrinoid sequence. All these are large, the laterals being somewhat larger than the median plate. The *post IR* is at its widest at this level. In the succeeding row the two central plates are the largest, flanked by one plate on the left and two irregularly placed, small plates on the right. Distad the rows of irregularly defined plates decrease in size and number. In the other interradii the first interbrachial is large, followed by two smaller plates. Distad the area narrows rapidly and is filled by a few much smaller, irregularly disposed plates. There are one or two *iIIBrr* both in the two-rami rays and between the pairs of brachial groups in the four-rami rays.

Judging by the arm bases, the rami were unusually stout for a camerate crinoid of this size.

Horizon and locality.—The specimens were collected by G. Arthur Cooper from the upper Alpena limestone (Traverse group) in the Michigan Alkali Quarry near Alpena, Michigan. More definitely, they were found in the uppermost beds of the formation between the coral reefs.

Types.—The holotype and paratype are in the collections of the United States National Museum; holotype No. 111627, paratype, No. 111628.

Pithocrinus waliszewskii (Oehlert), new combination.

Megistocrinus waliszewskii Oehlert 1896, p. 818, Pl. 26, Figs. 1-4.

Devonian. Santa Lucia, Leon Province, Spain. (Middle Devonian.)

Apparently prior to his description of the species, Oehlert sent photographs and an excellent plaster cast of the crinoid to Wachsmuth. On the basis of this material Wachsmuth advised Oehlert not to make a genus for the reception of the species, but to refer it to *Megistocrinus*. Oehlert himself rec-

ognized the striking dissimilarity of his species to *Megistocrinus* but deferred to Wachsmuth's judgment With the preparation of the Camerata monograph well in hand and the criteria for differentiating the genera established, it is difficult to understand Wachsmuth's decision. In any case the crinoid is unmistakably referable to the genus *Pithocrinus* here described.

Oehlert states that his figures are slightly enlarged This is misleading. The figures are nearly one and one-half times enlarged. The specimen is somewhat crushed and distorted, but otherwise is in an excellent state of preservation. Oehlert's illustrations and descriptions are excellent.

Through compression the tegmen appears almost flat, with depressed areas in the interradial areas excepting the posterior. Normally the tegmen would be somewhat convex. There seems to have been an anal tube of moderate size. The anal tube normally would be subcentral in position. Even with the distortion, it is not far from that. The arm groups are clearly separated by narrow gaps except in the posterior interradius. Here the space is much wider than in any known species referred to the genus.

In the *l post R* there are but three rami, one ramus being suppressed in one-half the ray. In the *r post* and *ant RR* there are four rami. In the *r* and *l ant RR* there are two rami. In the four-armed *RR* there are two *IIBrr*.

The species agrees well with the other forms referred to the genus except for the width of the posterior interradius. If this is an individual of medium size, as it may well be, one would expect a narrowing of the *post IR* at the periphery in later ontogeny.

Pithocrinus intrastigmatus (Schmidt), new combination.

Saccocrinus(?) intrastigmatus Schmidt 1931, p. 21, Text-fig. 9, pl 4, Figs. 5a-c, 6, 7.

Arnao limestone "Lower Devonian." Cap La Vela, Concha de Arnao, El Mugaron. Near Avilés, Prov. Asturias, Spain. (Middle Devonian.)

This species is based on three imperfect and badly preserved specimens. There can be little doubt, however, that the species is referable to *Pithocrinus*. The most interesting structural feature is that Schmidt gives a count of four rami in each ray.

Pithocrinus bifrons (Schmidt), new combination.

Megistocrinus (?) *bifrons* Schmidt 1931, p. 23, Pl. 4, Figs. 8a-c.

Arnao limestone "Lower Devonian." El Mugaron, Concha de Arnao, near Avilés, Prov. Asturias, Spain. (Middle Devonian.)

This species is based on the badly crushed basal portion of a dorsal cup. It certainly is not *Megistocrinus*, and such characters as it shows indicate *Pithocrinus* rather than any other known genus. It may even be a large individual of *P. intrastigmatus*.

CADISCOCRINUS, new genus.

Genotype.—Cadiscocrinus southworthi, new species.

Theca. Small, subcylindrical, typically somewhat constricted medially, and with a flattened flaring base. The basal area is deeply excavate. In basal view the basal circlet usually has a distinct pentalobate to stellate outline.

IBB. Five, forming a small disk situated at the apex of the cone formed by the invaginated proximal moieties of the *BB*.

BB. By far the largest plates in the dorsal cup. The proximal portions of the *BB* are flexed inward, giving a deeply invaginate base. In most of the forms known the *BB* are laterally produced, giving a pentalobate to stellate outline in basal view.

Radial series. The *RR* are of medium size, but appreciably smaller than the *BB*. The *IBrr* are relatively very small. Two uniserial secundibrachs may be incorporated in the cup. Distad the rami are compactly biserial. The rami are smoothly rounded dorsad, with somewhat flattened sides.

Interbrachial series. In all the interradii the proximal interbrachials rest on the truncated distal faces of the basals. In the posterior interradius the first anal plate is approximately the size of the other primary interbrachials. It supports a somewhat smaller median plate flanked on either side by two very small plates. In the third range, passing beyond the dorsal cup and forming part of the tegmen, is a median plate somewhat smaller than the median plate of the second range. In the other interradii the primary interbrachial supports two small plates in the second range. Distad the interradius narrows rapidly, and there are either no other interradials in the cup or a few very small plates.

Column. The column is stout for a crinoid of this size. It is circular in section and, as seen, composed of alternate nodals and internodals. The columnals are low. The lumen is small and appears to be circular in section.

Stratigraphic and geographic distribution.—The genus at present is known in the Middle Devonian of Ontario, Michigan, and Indiana.

Relationships.—Of the older described genera *Cadiscocrinus* may be compared only with *Rhodocrinus*, as currently recognized, or *Acanthocrinus*. I have recently (1944) proposed the genus *Cribanocrinus* for the reception of a group of lower Mississippian species formerly referred to *Rhodocrinus*. *Cribanocrinus* more nearly resembles *Cadiscocrinus* than either *Rhodocrinus* or *Acanthocrinus*.

Rhodocrinus and *Acanthocrinus* are essentially alike in gross structure, and a comparison with *Rhodocrinus* will serve for both. *Rhodocrinus*, as for current usage, has a flattened or excavate base. The sides of the cup are nearly vertical, or diverge distad. The *BB* and *RR* are of moderate size. The *IBrr* are large and *IAxx* moderately so. Typically three or more *IIBrr* are incorporated in the cup, and intersecundibrachs are present. The interradial areas are large, with numerous *iBrr* that merge with the *iAmbb*. The cup is typically ornamented with a network of radiating ridges. The rami have very low uniserial *Brr* continuing distad well above the cup and to the first bifurcations. Above the first bifurcations the rami are compactly biserial. The rami are relatively small. It will readily be seen that there is little resemblance between these structures and those of *Cadiscocrinus*.

Cribanocrinus has a subglobose to urceolate or ovate theca. The maximum diameter of the cup is at about one-half its height, or lower. The minimum diameter of the cup is at the level of the arm bases. The *IBB* are small. The *BB* are large, either larger or smaller than the *RR*. The *IBrr* and *IAxx* are relatively small. The interradial fields are narrow at the base, widen distad, and then narrow again. Occasionally there is a poorly defined median row of plates in the post *IR*, but this is exceptional. The rami are uniserial below and compactly biserial above the first bifurcations.

The most obvious differences between *Cribanocrinus* and *Cadiscocrinus* are in the shape of the dorsal cup, the arm structure, and in the great size of the *BB* in *Cadiscocrinus*.

The dorsal cup of *Cadisocrinus* is subcylindrical and typically somewhat constricted medially. With the exception of the first two uniserial *IIBrr* the rami are compactly biserial. The *BB* are by far the largest plates in the cup. Typically, *Cadiscocrinus* has a well-marked, median, linear series of plates in the posterior interradius.

Remarks.—There are two other undescribed species referable to *Cadiscocrinus* in the Springer collection. One is from the Norway Point formation of the Traverse of Michigan. One is from Clark County, Indiana, probably from the Beechwood formation. I collected the Michigan specimen many years ago. It was found about 1 mile downstream from the old Seven Mile Dam on Thunder Bay River. The locality as well as the old Seven Mile Dam is now submerged by the impounded waters of the Norway Point Dam. This specimen is an imperfect, somewhat crushed, dorsal cup. It is undoubtedly referable to *Cadiscocrinus* and does not differ greatly from the Ontario species. The species from Clark County, Indiana, is a very striking form. It is an incomplete dorsal cup, preserving the *IBB*, *BB*, four *RR*, and a few *iBrr*. The cup was low and broad, having an estimated diameter of at least 15 millimeters and a height of perhaps not much more than 9 millimeters. The plates of the cup are elaborately ornamented. High, sharp carinae pass from plate to plate, and there is a median carina on each basal, extending well down into the deep basal cone. The surfaces of the plates between the carinae are strongly papillose. All the structures preserved indicate that this specimen is referable to *Cadiscocrinus*.

Cadiscocrinus southworthi, new species.

Plate 1, Figs. 1-3.

This species is based on two well-preserved thecas, with portions of the arms attached. The holotype is slightly crushed. The paratype, not figured, is somewhat larger and not crushed. It is, however, partially replaced and encrusted with iron, probably limonite after pyrite.

The dorsal cup is subcylindrical, with a flat, flaring base. Medially there is a slight constriction. The basal area is deeply excavate, the *IBB* lying at the apex of a cone the wall of which is largely composed of the inwardly flexed proximal portions of the *BB*. The tegmen is unknown, being concealed

by the closely packed proximal portions of the arms. The species is small, the dorsal cup of the larger specimen having a height of 6 millimeters and an average diameter at the arm-bases of 8 millimeters. The specimen shows no juvenile characters and may be assumed to be adult.

The *IBB* are small and completely hidden by the proximal columnal. They lie at the apex of the deeply invaginated base and appear to be at approximately the level of the *IAx*. The *BB* are by far the largest plates in the cup. In the larger specimen, the paratype, a basal measures 2.6 millimeters in height by 4.6 millimeters in maximum breadth, as shown in the outer wall of the cup. The inner invaginated portion of the basal extends to a greater height. Each basal supports an interbrachial. The *BB* flare outward in a horizontal plane. In basal view each is produced into a subtriangular projection, giving the base a sharply stellate outline.

A radial in this same specimen has a height of 2.4 millimeters and a breadth of 3 millimeters. In the same series the IBr_1 has a height of about 0.9 millimeter and a breadth of 2.5 millimeters. The *IAx* has a height of 0.9 millimeter and a breadth of 2.2 millimeters. In the paratype the first two secundibrachs in each half-ray may be considered incorporated in the cup. In the holotype only the first is incorporated. The two proximal *IIBrr* are uniserial and stout.

In one interradius of the paratype the first interbrachial has a height of 1.7 millimeters and breadth of 2.4 millimeters. It supports two much smaller plates. This structure holds for all interradii except the posterior. In the next range there may be from one to three small plates at the level of the $IIBrr_1$. The *post IR* of the holotype shows the plates more clearly than the paratype. The primary anal plate is of approximately the size of the first interbrachials. In the median line it bears a somewhat smaller plate that is flanked on either side by a very small plate. The distal face of the second median anal plate lies at the level of the $IIBrr_2$. In the holotype the median anal of the second range supports a plate somewhat smaller than itself. This latter plate is tegminal.

As noted above, the two proximal secundibrachs are uniserial. A compactly biserial arrangement immediately follows them. The arms are stout, with rounded backs and somewhat flattened sides.

The column is proportionally large, having a diameter of

about 2.6 millimeters in its proximal portion in the holotype. The lumen is very small and seems to be circular in section The small amount of column preserved shows alternating nodals and internodals. The columnals are low.

Horizon and locality.—Both holotype and paratype were collected by Mr. and Mrs. Charles Southworth in the Arkona shale (Hamilton) at Hungry Hollow, 2½ miles east of Arkona, Ontario, Canada. The species is named in honor of the collectors, to whose zeal and patient collecting over a period of many years we owe chiefly our knowledge of the crinoids of this area.

Types.—The types are in the Springer collection in the United States National Museum; holotype, S 4440a; paratype, S 4440b.

GRIPHOCRINUS, new genus.

Genotype.—*Rhodocrinus* (*Acanthocrinus*) *nodulosus* Hall.

Theca. Composed of heavy plates. Dorsal cup subturbinate to cupuliform. Tegmen low, composed of many small plates, incompetent. Anal opening excentric. Anal tube unknown. If present, it was small. Plates of dorsal cup convex to tumid, with a tendency to form large median tubercles. There may be indistinct radiating ridges on the plates.

IBB. Small, but clearly visible in lateral view.

BB. Large. In some specimens all the *BB* make contact with the first interbrachials. In others a variable number of *BB* make contact.

Radial series. *RR* large, followed by two somewhat smaller *IBrr*. In adult individuals there are usually three or more *IIBrr* incorporated in the cup.

Interbrachial series. In the post *IR* the anal rests on *post B* on a broad face. In the second range there are three plates, followed in the third range by four or more. The median vertical row of anal plates is clearly defined, the plates gradually decreasing in size distad. The *post IR* is broad, reaching its maximum width at about the level of the *IAxx*. In the other interradii, as noted above, all the first *iBrr* may make contact with the *BB*, or a variable number of them may do so. These interradii are considerably narrower than the *post IR*, with two plates in the second range and two or three in the

third range. There is still a fairly wide spacing at the level of the fixed brachials, however. There are a number of *iIIBrr.*

Arms. The arms are relatively short, stout, with rounded backs, and branch irregularly two or more times. The arms are compactly biserial, beginning with about the third or fourth *IIBr.*

Column. The column is large, circular in section, with a large pentalobate lumen.

Stratigraphic and geographic distribution.—*Griphocrinus* at present is known in the Middle Devonian of New York, Kentucky, and France. The French horizon was given by Oehlert as Lower Devonian, but with us it would be Middle Devonian. To this day horizons in Europe are called Lower Devonian that in America we would place unequivocally in the Middle Devonian.

Relationships.—*Griphocrinus* has slight resemblance to or relationship with *Rhodocrinus*, to which it has been referred. A brief summary of the characteristics of *Rhodocrinus* are given under the description of *Cadiscocrinus*. The subturbinate cup of *Griphocrinus*, with its exsert base, and particularly the structure of the arms separate the genus from all known genera of the Rhodocrinidae. The reference of *G. halli* to *Thysanocrinus?* and the doubtful reference by Wachsmuth of the French species to *Rhapanocrinus* seem to indicate more nearly the relationships of the genus. *Griphocrinus* may, I think, be considered an end term in the line of the Dimerocrinidae or a similar stock in which the first interbrachials of the interradii, other than the posterior, have migrated wholly or in part downward between the radials and come in contact with the basals. This structure, at one time held by Carpenter and others of prime importance, can be overemphasized and must be considered in combination with other structural features and the stage in the evolution of the group I would then temporarily place *Griphocrinus* in the Dimerocrinidae as more nearly indicating its genetic affinities.

Griphocrinus halli (Lyon), new combination.

Rhodocrinus halli Lyon 1862, p. 412, Pl. 4 Figs. 5a, b

"Crinoid bed, lying between the Hydraulic limestone and the Blackslate: Beargrass quarries; Jefferson county, Kentucky" (=Beechwood limestone).

Rhodocrinus(?) *halli* Wachsmuth and Springer 1881, p 212.

"This species is certainly not *Rhodocrinus* . . . " "Niagara group."

Thysanocrinus? *halli* Wachsmuth and Springer 1897, p. 196, Pl. 13, Figs. 9a, b.

"Niagara group?"

Dimerocrinus halli Bassler 1915, p. 439.

"Niagaran (Louisville)."

Dimerocrinus halli Springer 1926, p. 14.

"Louisville limestone."

Goldring (1924, Pl. 2, Fig. 2) figures the holotype of *G. halli* as a specimen of *G. nodulosus*. There is no mention of the specimen in the text or of the species in the synonymy. Although the two species are similar, I think they may be held distinct. If not, Lyon's species has priority.

The age assignment of "Niagaran" or "Louisville limestone" for *G. halli* is quite unjustified. Lyon (1862, p. 412) states that the species was found by Knapp "in the same beds as specimens described in this paper under Nos. 43, 44 and 49." No such numbers are shown in the text, but the only three species to which Lyon's statement could apply are "*Cyathocrinus leviculus*," "*Cyathocrinus wortheni*," and "*Actinocrinus cassedayi*." For the first of these species Lyon gives the horizon and locality cited above. The horizon in modern terminology would be the Beechwood limestone of approximately Hamilton age.

Griphocrinus insculptus (Goldring), new combination.

Rhodocrinus insculptus Goldring 1935, p. 349, Pl. 25, Fig. 1.

Hamilton (Tichenor or Moscow), 2 miles east of Alden, Genesee County, New York.

Griphocrinus nodulosus (Hall), new combination.

Rhodocrinus (*Acanthocrinus*) *nodulosus* Hall 1862, p. 126.

"Hamilton group, Ontario County, N. Y." (Approximately Tichenor horizon).

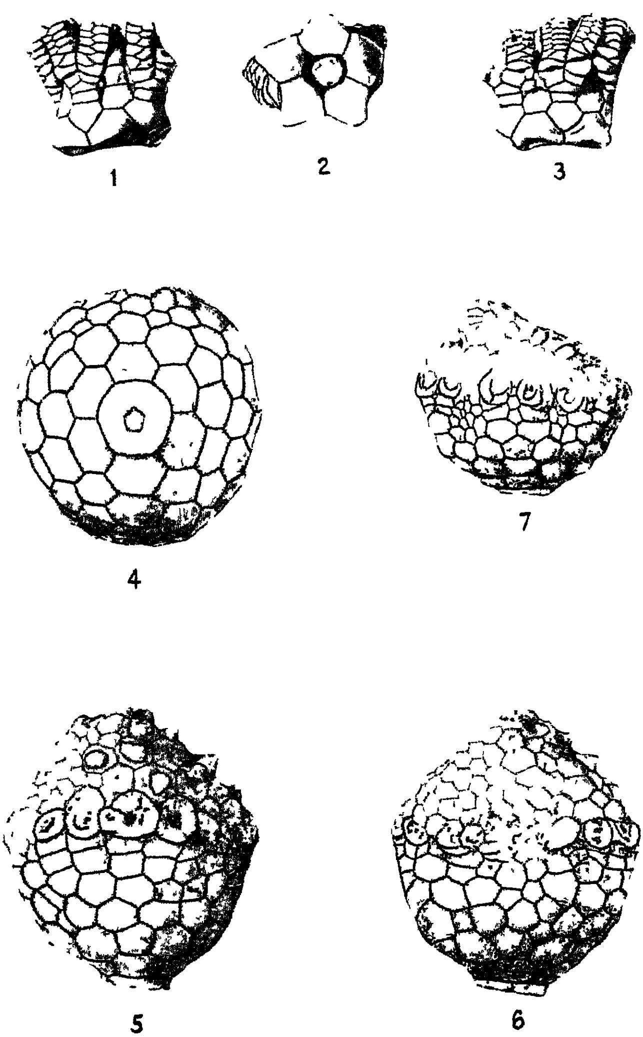
Rhodocrinus (*Acanthocrinus*) *nodulosus* Hall 1872, Pl. 1, Fig. 8.

Rhodocrinus nodulosus Wachsmuth and Springer 1881, p. 212 (386).

Rhodocrinus nodulosus Wachsmuth and Springer 1897, p. 225, Pl. 13, Fig. 8.

Rhodocrinus nodulosus Goldring 1924, p. 89, Pl. 2, Figs. 1, 3-5 (*non* Fig. 2=*Griphocrinus halli* (Lyon)).

Dimerocrinites nodulosus Bassler and Moodey 1943, p. 425.



EXPLANATION OF PLATE

FIGS 1-3 *Cadiscocrinus southworthi,* new genus and species: 1, posterior view of holotype, 2, basal view; 3, anterior view All figures x 2

FIGS 4-7 *Pithocrinus cooperi,* new genus and species 4, basal view of holotype, 5, right posterior view, 6, posterior view; 7, right posterior view of paratype All figures natural size

Griphocrinus wachsmuthi (Oehlert), new combination.
Raphanocrinus? wachsmuthi Oehlert 1887, p. 68, Pl. 1, Figs. 10, 11, Text-fig. on p. 69.

Sablé (Sarthe), France. "Lower Devonian," (In America the horizon would be Middle Devonian.)

On the advice of Wachsmuth, Oehlert provisionally referred this species to *Rhaphanocrinus*. Wachsmuth and Springer (1897, p 259) mention the species under their discussion of the genus *Raphanocrinus* and state that "this is apparently not a typical form."

The specimen is a fairly well-preserved theca. The description and figures show a crinoid that agrees well with *Griphocrinus*. It certainly were better placed here than under *Rhaphanocrinus*, to which it bears but slight relationship

AMBICOCRINUS, new genus

Genotype—*Thysanocrinus arborescens* Talbot.

Ambicocrinus arborescens (Talbot), new combination.
Thysanocrinus arborescens Talbot 1905, p. 23, Pl. 1, Fig. 2, Text-fig. 1.

Coeymans (Lower Devonian), North Litchfield, New York. (Manlius-Upper Silurian(?).)
Dimerocrinus arborescens Goldring 1924, p. 83, Pl. 1, Fig 1

The type species has been described and figured by Talbot (1905) and Goldring (1924). Goldring has explained the difficulty in getting an adequate illustration of the type. On the whole, the figure is good, though somewhat sketchy in detail.

Ambicocrinus may be compared only to *Dimerocrinus*, *Eudimerocrinus*, and *Diamenocrinus* among described genera. In *Ambicocrinus* the plates of the dorsal cup are relatively thin, giving an incompetent structure. The plates are smooth, and there is no ridge traversing the radial series. The *IIBrr* are incorporated in the cup up to at least the third brachial There are numerous intersecundibrachs. The rami divide one or more times above the first bifurcation and are compactly biserial The column of *Ambicocrinus* is substellate in section.

Eudimerocrinus, as pointed out by Springer in making the genus, differs from *Dimerocrinus* only in having branching rami. In typical *Dimerocrinus* and in *Eudimerocrinus* there is a well-defined keeled ridge traversing the plates of the radial

series and passing on to the basals. The interradii typically show as somewhat depressed areas. The plates of the cup are typically moderately thick and may be very heavy. Intersecundibrachs are few in number, and the rami are seldom incorporated in the cup above the $IIBrr_2$. The column is circular in section.

Diamenocrinus has a strongly ornamented cup. The peculiar biserial arms, appearing uniserial as viewed from above, are one of the characteristic features of the genus. As in *Ambicocrinus*, the column is substellate in section, and the rami have many divisions.

Ambicocrinus may be held within the Dimerocrinidae as a matter of convenience. Substellate or pentagonal columns are a rarity among the Camerata. There is a possibility that *Ambicocrinus*, *Diamenocrinus*, and even *Thylacocrinus* may be members of a tenuous evolutionary line running parallel to the true *Dimerocrinus* stock.

Geologic distribution.—*Ambicocrinus* is known only from the prolific crinoid beds near Litchfield, Herkimer County, New York. The horizon is given as Coeymans and placed in the Lower Devonian. There is some uncertainty as to this assignment, however. The horizon may be Manlius and referable to the high Silurian. I have collected specimens of the associated *Ctenocrinus pachydactylus* in place at Schoharie, New York, and although the horizon is somewhat questionable the evidence was rather in support of a Manlius assignment.

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REFERENCE NOTE

* It will be noted that I give the date 1862 for Lyon's paper instead of 1861, as has been given in the past

The running date of "Dec 1861" at the bottoms of the pages is simply an indication that these pages are part of the Proceedings of that month and do not give the date of issue. It will be noted that in the account of the meeting of December 10, 1861, Lyon's paper was presented for publication. In the Proceedings for 1862 (1863) at the meeting of February 18 (p. 20) it is stated that "Mr Vaux, on behalf of the Committee on Proceedings, laid on the table the No for last December" Lyon's paper should thus have the date February 1862 instead of December 1861.

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Correction—In my paper "*Aphelecrinus*, a new inadunate crinoid genus from the Upper Mississippian," Amer. Jour. Sci., April 1944, there is an erroneous designation in the plate description. The new species *Aphelecrinus oweni* (p 198) appears on the plate (Pl 1, figs 1-3) as *Aphelecrinus lyoni*, n. sp The trivial name *lyoni* on the plate should be changed to *oweni*.

Edwin Kirk.

SCIENTIFIC INTELLIGENCE

PALEONTOLOGY.

Tempo and Mode in Evolution; by GEORGE GAYLORD SIMPSON. Pp xviii, 237; 36 figs. New York, 1944 (Columbia University Press, $3.50).—Two previous volumes of the Columbia Biological Series, by Prof. Theodosius Dobzhansky and by Dr. Ernst Mayr have considered the mechanisms of evolution. Both these books have excited wide interest and admiration. Dr. George Gaylord Simpson has now added a third evolutionary study to the series which fully maintains the high standard of excellence set by his predecessors. While the two previous books incorporated in their titles that of Darwin's classical work, Doctor Simpson's title significantly does not include the words "Origin of Species." His work is in fact a bold and highly successful attempt to apply population genetics to the problems presented by the evolution, not of species but of the larger categories of taxonomy. After considering the available data on the absolute and relative rates of evolution, a study is made of the distribution in time of the genera of Carnivora and of Pelecypod mollusks. It is shown that such genera considered statistically show a characteristic persistence in time, so that a survivorship curve can be drawn indicating what proportion of the genera existing at any one time can be expected to exist at a given later time From such a distribution, based entirely on extinct genera, it should be possible to calculate the age composition of genera existing today. For the Carnivora the calculated and observed distributions are very similar, for the Pelecypoda an abnormally large number of living genera originated at a very remote time. There seem, then, in any given group to be two modes of evolution, the standard mode, characteristic of the group and called *horotelic,* and an abnormally slow mode, the *bradytelic,* which is, however, not exhibited by all major taxonomic groups. Moreover, extrapolation back in time of both horotelic and bradytelic lines indicates that they must have arisen by a *tachytelic* process, very much more rapid than that exemplified in their subsequent history. The rapid tachytelic mode of origin of major groups is practically unknown in the fossil record. The occasional fortunate find, as of *Archaeopteryx,* indicates, however, that no real discontinuity must be postulated. The difference between this sort of evolution, termed in the last chapter of the book *quantum* evolution, and the more usually observed *phyletic* evolution of the great sequences of vertebrate palaeontology is real. The difference, however, lies, not as Goldschmidt supposes, at the cytogenetic level, but rather at the level of population genetics.

The rarity of intermediates indicating the establishment of radically new lines, suggests that such new lines originated with great rapidity in small populations. The major phyletic sequences, showing a series of progressive lines that tend to follow a more or less constant direction on which most of palaeontology is based, represent processes occurring in large populations Following the general theoretical conclusions of Haldane, Fisher and notably of Wright, Simpson indicates that the tachytelic origin of a new group is due to the random fixation of genes in small populations leading occasionally to a preadaptation to a new type of ecological niche. The more usually observed phyletic type of evolution consists of perfection, by natural selection, of the new adaption through a long series of forms constituting large populations, in which selection is likely to be of paramount importance in controlling evolutions The occasional apparently immortal bradytelic genera like *Nucula* and *Ostraea* form large populations in practically unvaried habitats

This main thesis is expounded with a wealth of illustrative detail and with an outline of the theoretical background that must be taken into account Certain special features of interest arise in the discussion There is no indication that mutation rate controls phyletic evolution, though it may conceivably do so in the tachytelic quantum stage. Throughout the great well-known sequences of phyletic history known mutation rates of the order of 1 in 10^6 are quite sufficient to account for all observed changes. It is surprising to find that there is no indication that generation length has any clear effect on evolutionary rates It may perhaps be suggested that rapidly breeding forms tend to be small and so in general numerous, and their effective breeding populations may actually be greater than the theoretical optimum postulated by Wright. An analogous suggestion may be made that populations of herbivores in general are likely to be larger than those of their predators. A study of certain lines such as the Machairodontinae and their prey, along these lines, might be profitable. The work of Elton and its systematization by Lindeman may well prove of interest to palaeontologists in this connection Simpson rightly calls attention to the potential importance of cyclical fluctuation in numbers of animals.

To the present reviewer the validity of the bradytelic Pelecypod genera is not entirely convincing; it seems possible that they represent groups in which the main lines of advance concerned only the soft parts Even in the most favorable cases conchological genera cannot have the validity of the mammalian osteological genera that form the main basis of the argument. It may appear captious to call attention to a minor typographical blemish, but as it might constitute an obstacle to those not acquainted with theoretical population genetics, its correction is important. On pages 66-67 the

expression "half the reciprocal of the breeding population" is written symbolically as if "half the breeding population" were meant, and so for the other fractions employed. On later pages a somewhat better typographic usage is followed. In spite of the footnote on page 198, the reviewer cannot help thinking that the continued use of the word *phylum* in two entirely different senses is not likely to promote understanding between palaeontologists and neozoologists.

Tempo and Mode in Evolution is the most important contribution to evolutionary theory to come from Palaeontology since the days when the fossil record was first used to demonstrate that evolutionary change must have taken place. It is also a highly important contribution to population genetics, because by showing that what took place is what would be expected, on the basis of the mathematical theory, the latter receives a remarkable objective confirmation. The book must be studied thoroughly by everyone concerned with the mechanism of evolution G. E. HUTCHINSON.

Methods in Climatology; by VICTOR A CONRAD. Pp. 228. 46 figs. Cambridge, Mass., 1944 (Harvard University Press, $4.00).

Climate of Indiana; by S. S. VISHER. Indiana University Publications Science Series No. 13. Indiana University, Bloomington, Indiana, 1944 (Indiana University Bookstore, $4.00).—Two books on climate received at practically the same time supplement each other most interestingly. *Methods in Climatology,* by Doctor Conrad, is purely statistical. On the jacket the claim is made that the book is of special value in prosecuting the war, but the main value lies almost entirely in days of peace when weather observers, graduate students, and college professors can devote months and years to analyzing climatic records. Doctor Conrad has reduced the methods of analysis to simple forms with a minimum of mathematics. Nevertheless the ordinary graduate student or weather observer will consider the book quite mathematical and will have to study it most carefully in order to get the great benefits which it undoubtedly offers. The book is full of valuable suggestions.

The title, *Methods in Climatology,* creates a misapprehension. The author seems to realize this, for at both ends of the book he apologizes for omitting so much. No apology would be needed if the book were called "Methods of Preparing Climatological Statistics."

Doctor Conrad's primary interest lies in climatic averages and departures from such averages. He pays practically no attention to the foremost climatic problems of our day such as cycles of weather aside from those of the day and year, and the relation of weather and climate to crops, animal abundance, season of birth, health, business, and other organic conditions. The section of "Bio-

climatology" is only half a page, and gives no hint as to how climatic statistics are to be correlated with the growth, health and activities of plants, animals and man. The book is excellent as far as it goes, but it stops short just when it gets to the most interesting and difficult parts of climatology.

If we did not know that Professor Visher's *Climate of Indiana* was written with no knowledge of Doctor Conrad's book, it would almost seem as if the first three hundred pages were written as an illustration of the results that are attained through intelligent use of methods such as are described by Doctor Conrad. Professor Visher says practically nothing about methods; he merely uses them. His book nominally describes merely the climate of Indiana. Actually, however, it provides an outstanding illustration of the way in which the climate of all parts of the world ought to be described. In the whole literature of climatology no other book gives so good a description of the climate of an individual region. The first 335 pages are devoted to the statistical phases of the subject, but with a good deal of incidental material as to the effect of unusual or extreme conditions. The completeness of this part of the book is illustrated by the fact that it contains 407 illustrations, most of which are little maps of Indiana. From the maps and tables one can find out hundreds of facts as to any part of the state—not only what the average temperature and rainfall are, but what the extremes have been, what damage is done by hail or lightning, how frequently there is a rainfall of 2½ inches in one day, let us say, and innumerable other interesting facts. Moreover, Professor Visher sums up these facts in such a way that they form part of a broad picture which is of much value to the general reader as well as to students of climatology.

The most interesting part of *Climate of Indiana* is pages 336-461. There Professor Visher treats such special topics as "The Climate of Seven Legal Holidays," climatic changes in Indiana compared with those of the world as a whole, and the effect of climate upon the form of the land, the yield of crops, and human health. Finally, Indiana is divided into three climatic regions, south, central, and north, with three sub-regions in each from east to west. Tables for chief cities complete the book. This well printed and handsomely bound volume should serve as a model for climatologists all over the world.

ELLSWORTH HUNTINGTON.

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American Journal of Science
JULY 1945

GEOLOGICAL AND ECOLOGICAL OBSERVATIONS OF SOME HIGH PLAINS DUNES.

HAROLD M. HEFLEY AND RAYMOND SIDWELL.

ABSTRACT. The following points are revealed by the study 1 The dunes are apparently of local origin and derived from the erosion of subjacent Tertiary sediments 2 They were originally covered by the climatic climax mixed grass association except where edaphic conditions supported a relict biota characteristic of more mesic grasslands. 3 The relict vegetation has maintained itself locally since the present climatic conditions became established because the water table is almost at the surface in some places. 4 The present condition of both substratum and biota is greatly altered. Natural conditions have been disturbed by overgrazing, the effects of which are all the more pronounced because of the apparent progressive increase in aridity since the initiation of the present climatic cycle

INTRODUCTION.

A SAND DUNE area about 125 miles long and eight miles wide at the widest part extends from the east-central portion of New Mexico into eastern Bailey County, Texas (Text Fig. 1). It has an average altitude of 3400 feet and is a part of the High Plains. The contained dunes are low and isolated in the westernmost end of the belt but become larger and more concentrated a few miles to the eastward. Near Portales, New Mexico, two roughly parallel dune belts arise and fringe the dune area. These extend into Hale County, Texas. Each belt is about a mile wide, and contains large, closely spaced dunes, many of which are migrating. The dunes between the fringing belts are lower, less active, and more widely spaced.

The entire dune area is restricted to a broad series of shallow basins commonly known as Portales Valley. It was excavated by a stream since captured by the Pecos River (Meinzer, 1923). Porous materials deposited by the former stream partly fill the basin and constitute the present shallow ground water horizon. The water level ranges from three to 35 feet

beneath the soil surface (Texas State Board of Water Engineers, 1938).

METHODS AND PROCEDURES.

Ecological terminology follows that of Clements (see Carpenter, 1938). The nomenclature of Ecology is not yet completely stable, and the senior author believes the system devised by Clements is the most logical extant. The geological terminology follows accepted forms.

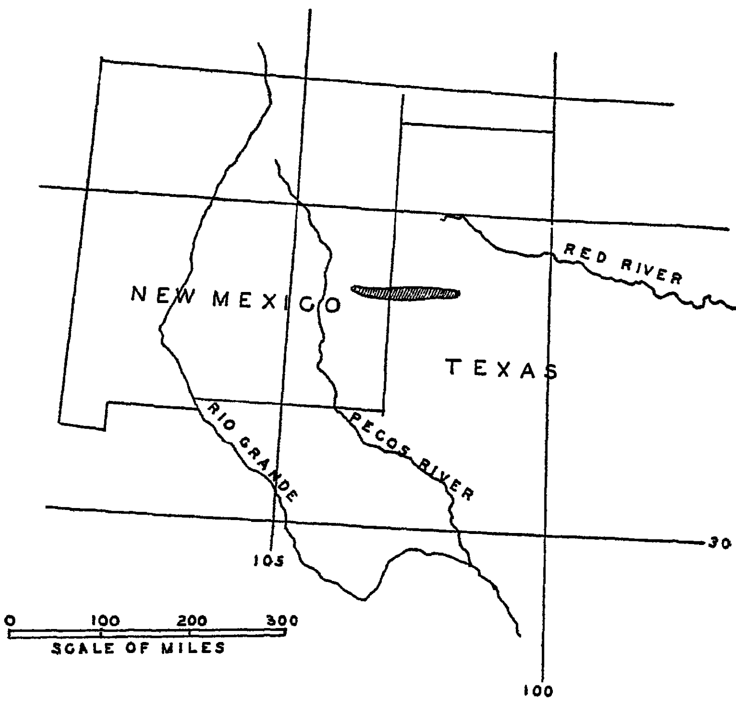


Fig 1. Map showing location of the dune area

The writers visited the area together and separately. The ecological portion of the work (for which the senior author is responsible) presumes to describe the communities as they now exist. Field work consisted of observations, transects, and collections of organisms not immediately recognizable in the field. These were brought to the laboratory and identified. Geological work (that of the junior author) consisted of determining the height, shape and pattern of various dune types, their rela-

tion to one another, and also collection of samples from various parts of representative dunes Twenty-five grams of each sand sample was weighed in the laboratory, then sieved to determine size grades. Heavy minerals were isolated with bromoform, then identified with binocular and polarizing microscopes. The individual grains, especially quartz, were classed as rounded, sub-rounded, sub-angular and angular on the basis of abrasive wear.

GEOLOGY

The climate of the sand dune area is classified as semi-arid, with a mean annual precipitation of less than 16 inches Maximum precipitation occurs during May, June, July, and August. Maximum wind velocity obtains in late spring and early summer, reaching an average of 185 miles per day in March, 196 miles per day in April, and 193 miles per day in June

The entire dune area overlies late Tertiary and Pleistocene sediments. The basal materials, probably Pleistocene, are chiefly fluvial in origin and consist of unconsolidated clays, sands, and gravels. Caliche caps these materials, is light colored, and consists mainly of calcium carbonate, silica, sand, and clay minerals. The basins contain deposits which are probably early Pleistocene. These consist of sand, clay, and thin beds of volcanic ash.

Dunes fall into three distinct series: blowout dunes, shrub-coppice dunes, and active transverse dunes (Melton, 1940). Active and anchored blowout dunes which include crescent shaped ridge and basin, elongated, and oval shaped ridge and basin dunes are well represented. Active crescent shaped ridge dunes are the most conspicuous as well as highest in the area. They are located on the leeward side of depressions with the crescents opening into the prevailing winds. The leeward front is rounded and much steeper than the slope to the windward Most anchored dunes are rather circular in outline with the vegetation cover partially obscuring both windward and leeward portions. The underlying materials (hard compact clay or loose partially consolidated sand) and the position of the ground water table largely control the depth of depressions and the height of adjoining sand ridges. If underlying materials consist of pack sand and sub-surface water is absent, well developed sand ridges and deep depressions dominate the landscape Many crescents have been obscured by vegetation cover

and shifting sand, hence anchored dunes usually appear as elongated mounds.

Elongated blowout dunes are similar to crescentic sand ridges in that they are located on the leeward sides of depressions with the crescents opening into the prevailing winds. Such dunes consist of elongated ridges with a maximum height of 20 feet and an average length of 300 feet.

In areas where dunes of one or more types are crowded together, blowout oval shaped ridges have developed which partially or completely enclose depressions. The pattern formed is probably a modification of the upsiloidal dune type described by Smith, 1939. Three sides of many ridges are anchored, but when closure is complete migrating sand occurs on the windward side. Dimensions of average closed oval ridges are about 300 by 220 feet with the highest part of the ridge 21 feet above the bottom of the enclosed depression.

Shrub-coppice dunes of the region are of two groups with respect to origin. When sand collects in and around scattered clumps of vegetation, small, usually somewhat elongated dunes are formed. These are rounded both to leeward and windward, and constitute the most common type. The sand is light in color and unconsolidated. The second type of shrub-coppice dune appears to have originated by recent active erosion of low established dunes probably of the blowout type. Such dunes are irregular shaped mounds with the leeward sides rounded, but the slopes are steep and irregular to the windward. The materials are partially compacted, and yellow.

Active transverse dunes occur in portions of the belt where eolian work is extremely active. These are elongated ridges, and are migrating east eight degrees south, which is transverse to the direction of the prevailing sand-moving winds (see Melton, 1940, Fig. 29). Some of these dunes consist of a single curving ridge which may be continuous for one-half mile or more. Others are irregular, discontinuous, and often branching. It is not uncommon for a given dune to progress from a single curving ridge to one that is irregular and broken.

In fixed dunes particle diameter range of $\frac{1}{4}$ to $\frac{1}{8}$ mm. is dominant compared with a range of $\frac{1}{2}$ to $\frac{1}{4}$ mm. in migrating dunes. Approximately 75 per cent of the sand is from $\frac{1}{2}$ to $\frac{1}{4}$ mm. in diameter on the windward side of migrating dunes while about 50 per cent of the sand grains are in this size grade

on the leeward side. The heavy minerals in fixed dunes are magnetite, garnet, epidote, tourmaline, zircon, ilmenite, hornblende, hematite, rutile and leucoxene in decreasing order of abundance. Garnets, tourmaline, epidote, zircon and leucoxene increase as much as 100 per cent in migrating dunes with other heavy minerals maintaining approximately the same proportions as in fixed dunes. The abundance of magnetite decreases from 65 per cent in stationary dunes to 25 per cent in migrating ones. Most quartz grains larger than 1/4 mm. in diameter are rounded or sub-rounded, many are frosted and a few are pitted. The majority with a diameter range less than 1/4 mm. are angular and iron stained. A few quartz grains show clouding in reflected light, caused by surface and crack alteration.

SOURCES OF THE SAND.

The basin-like areas where the dunes are located apparently received sediments as former drainage channels (Meinzer, 1923). Blue to gray shales, white sands and thin beds of volcanic ash now exposed in some places were probably deposited in former shallow lakes within the area (Antevs, 1935; Howard, 1935). These sediments, excepting iron stained quartz grains, are quite similar in texture and mineral content to the materials comprising the dunes, and are in all probability one of the sources of the wind-blown sand. Antevs, 1935, indicates that basal sediments in the area are practically untouched by erosion, but, despite this assertion, in many places within the basins, caliche and the underlying Tertiary sands are at the present time (1943, 1944) quite actively suffering scour. As a result, caliche fragments are abundant in certain dunes.

The heavy mineral suites of the Tertiary unconsolidated sands and the dune materials are quite similar except for a slightly greater abundance of hematite and hornblende in the former. Hematite and hornblende are not particularly stable, however, and could be changed or destroyed during transportation.

The dunes represent at least two stages with respect to time of formation. It is rather doubtful that these stages can be correlated with the formation of the Judkins and Monahans dunes investigated by Huffington and Albritton, 1941. None of the dunes in Portales Valley is conformable in age to the Judkins, since the sediments are of different size grades, and even the oldest established dunes in the Portales Basin are much steeper, and have suffered much less mass erosion. In Portales

Valley during the initial stage low dunes of the present stationary type are formed. They are characterized by fine texture of materials, 10 per cent clay and silt, and by the reddish brown color due to the abundance of iron coated sand grains.

Some fixed dunes have been enlarged by subsequent additional recent deposits while others have been partially or entirely destroyed by erosion. In active dunes clay is generally absent, and the color of the sand is light gray. At the present time, active dunes are the largest in the area and vegetation as well as older dunes are being destroyed by their migration. The dune area has extended itself eastward within the past few decades into eastern Hale County, Texas, where several square miles of former farm land has been covered by migrating sand.

ECOLOGY.

The present physiographic condition of the area has already been described in the geological portion of this paper Migrating dunes are without doubt the direct result of overgrazing during the past several decades. It is necessary, however, to comment briefly on the probable length of time the present climatic conditions have existed, since climate limits the kind, duration, and extent of climatic climax communities, while edaphic and biotic factors operating under the limitations imposed by climate control the direction and duration of succession.

Level areas within the dune belt are of two types: those with a mature soil and a caliche substratum, and sandy flats without such a caliche layer and for the most part situated above a shallow water table. Before grazing was extensive, the former areas probably supported a climatic climax mixed prairie biota characteristic of the High Plains. They are now covered by a disclimax of *Hilaria*, *Buchloe*, and *Bouteloua*, with *Mimosa*, *Acacia*, and *Prosopis* as subdominants. The latter areas are mostly covered with developmental communities leading to a relict edaphic climax of *Andropogon halli* and *Andropogon furcatus*.

Antevs, 1935, estimates that temperature conditions have been essentially the same as at present for the past 10,000 years, and that the moistest conditions the area has experienced within recent geologic time occurred about 15,000 years ago. His conclusions are probably as nearly correct as any, although his method of deduction, based as it is on several assumed

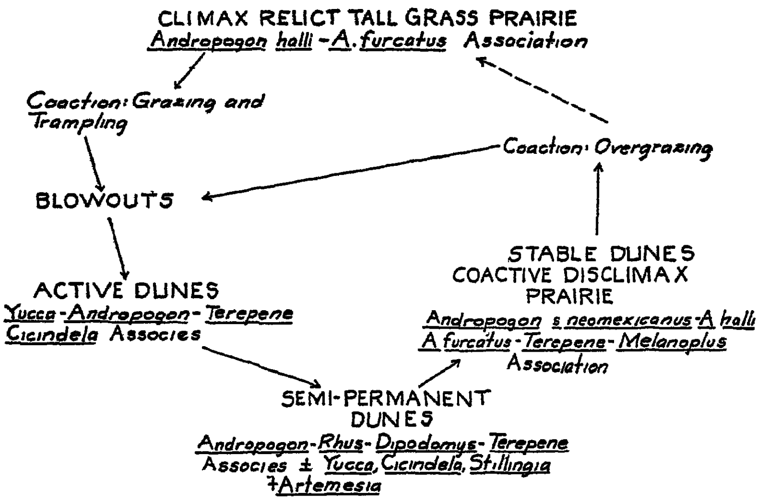
values, together with evaporation data taken elsewhere, leave much to be desired. Assuming that Antevs' dating of paleoclimate is correct, the locality would have a climatic age of approximately 10,000 years. During this time, the climax vegetation of the region with its associated animals became established. Assuming also that 15,000 years ago marked the beginning of a 5,000-year period of increased moisture (Antevs, 1935) coincident with the culmination of the Wisconsin Ice Sheet, the vegetation then was in all probability more mesic in character than now. Persistence of such vegetation as relict climax communities in local, edaphically controlled areas probably accounts for species now characteristic of the tall grass prairie being present in certain portions of the dune area.

The amount of available moisture apparently depends on the type and character of sediments beneath the dune area. In many places, dunes have migrated onto level land with a mature soil beneath which is a layer of caliche probably of Tertiary age (if Antevs' dating is correct, it could be early Pleistocene). The relative impermeability of such strata results in dunes above them being less moist than those located in areas where mature soil is absent, the caliche layer discontinuous or absent, and with the water table only slightly beneath the base level of the dunes

It is not evident that the geologic age of the several types of dunes correlates directly with the biota of the dunes. Vegetation on them (and therefore the animals) as well as the level areas they surround is controlled more by climate, the permeability of the underlying strata, and location in relation to the ground water table than by the geologic age of the substratum, granting sufficient time lapse for the vegetation to become stable. Dry, stabilized dunes support either the climatic climax mixed grass prairie biota, or a coactive disclimax biota without regard for the time of dune formation Most dunes support a relict edaphic climax association whether they are old, or relatively young The formation of active dunes and their accompanying blowouts has resulted in many developmental communities throughout the area These will now be considered.

Succession on Moist Dunes. Text Fig. 2 shows the general scheme of succession on moist dunes The pristine climax community was a tall grass prairie that arose when the climate

was mesic in character (Antevs, 1935). It now persists as a relict dominated by *Andropogon halli* toward the west, and a mixture of *A. halli* and *Andropogon furcatus* in eastern portions of the area. Subdominants are *Rhus trilobata*, *Stillingia sylvatica*, and *Prunus sp.* Sumac and sand plum are present where the moisture content is high, while *Stillingia* occurs where there is less moisture and the dominant grasses are more or less dwarfed.



Text Fig 2 Succession on Moist Dunes

The predominants of the entire dune area formerly included the bison, antelope, and probably deer. These are now gone except for a few antelope in one or two protected localities. Their niche has been filled to overflowing by range cattle. Influents in moist dune communities include *Terepene ornata*, (terrapin) *Dipodomys spp.* (Kangaroo rat), *Pituophis sayi* (Garter snake), *Thamnophis* spp. (Racers), *Crotalus confluentis* (Rattlesnake), *Calamospiza melanocorys* (Lark Bunting), *Callipepla squamata* (Blue quail), and *Sturnella neglecta* (Western meadowlark). Grasshoppers of various species also exert considerable influence on the community.

Moist dunes have been severely modified by the presence of cattle. Both physiographic and ecologic succession have been initiated, the later being coseral in character. Ground cover

Fig 1
Blowout on a moist dune Remnants of a former vegetated old dune are in foreground Hummock of younger stabilized dune in background

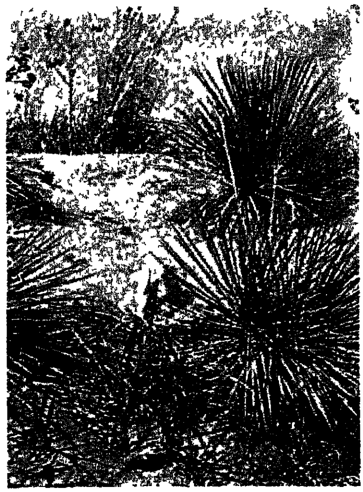


Fig 2.
Yucca on moist, young dune

Fig 3
Semi-permanent Moist Dune, *Andropogon-Rhus-Dipodomys-Terepene* Associes

Fig. 1
Partly vegetated blowout at the base of an old, dry dune of which only yucca covered hummocks remain.

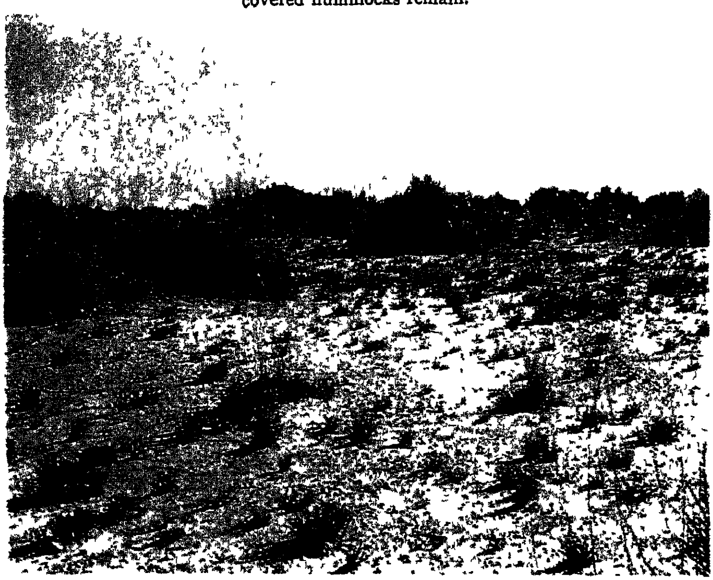


Fig 2.
Effects of grazing and intense trampling on a former dry dune

has been destroyed in many places both by grazing and trampling. Exposure of the ground surface has resulted in extensive blowouts where once were southwestern and western sides of the dunes (Plate 1, Fig. 1). Sand thus loosened has lodged amongst the vegetation on tops and sides of adjacent dunes, covering it completely in many instances. Migrating dunes result, together with blowouts that extend below the present water table in some places.

Should dunes so formed be located where a mature soil and an underlying stratum of caliche is absent, upward passage of moisture from the shallow ground water is rapid. This results in the presence of sufficient moisture to initiate a somewhat unique succession. Yucca is the first plant to appear, and isolated clumps of bluestem grass are usually present also (Plate I, Fig 2). Both plants arise from the roots and rhizomes of old, buried plants. This stage is rapidly followed by *Rhus trilobata*, which is deep rooted, and which is also spread by kangaroo rats gathering and storing the fruit (Plate 1, Fig. 3).

The box tortoise is the most conspicuous reptile in the associes at this stage. There are numerous burrowing insects present, which include mutillids, digger wasps, and tiger beetles. These likewise occur in blowout areas.

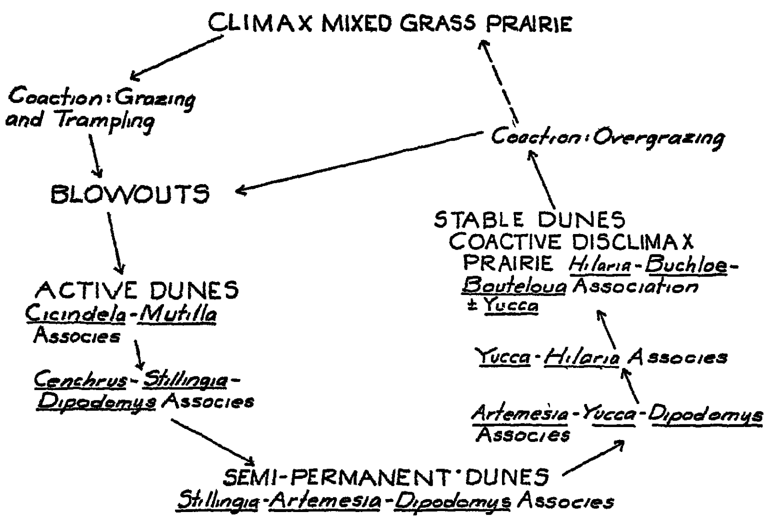
The advent of sumac, bluestem, and yucca once established brings about a semi-stable condition of the substratum, and subsequently sand sage (*Artemesia filifolia*) appears along with scattered bunches of the western bluestem, *Andropogon scoparius neomexicanus*. Moist dunes reach this condition probably two or three decades after initiation. Sage brush, and the increase in tall grasses furnish protection, and the animal components of the community increase as a result. Flocks of blue quail are frequently encountered, and a few western bob-whites were observed. Coyotes find suitable cover in the associes and cottontail rabbits are more numerous here than elsewhere in the area.

Decline in sand sage, and increase in the control of the community by tall grasses, initiate the sub-climax community on moist dunes. Under present conditions, however, it is preferable to refer to the succeeding community as disclimax, since grazing effectively prevents it from becoming a tall grass edaphic climax. Sand plum (*Prunus watsoni*) appears in this

disclimax and rarely in the preceding community, chiefly in areas that have been disturbed by coaction.

Succession on Dry Dunes. The formation of so-called "dry" dunes has been described earlier. They differ from moist dunes by being located above a relatively impervious stratum of caliche, with a mature prairie soil interposed between their bases and the caliche.

The climax association is apparently a faciation of the



Text Fig 3. Succession on Dry Dunes

mixed grass prairie, but is modified to some extent by overgrazing, even in areas where cattle have been excluded for many years. The dominant grasses appear to be the western little bluestem, *Andropogon scoparius neomexicanus*, *Sporobolus airoides*, the alkali drop seed; with *Sporobolus cryptandrus* present in many places almost to the exclusion of other mid-grasses. Subdominants are *Hilaria jamesi*, *Buchloe dactyloides*, and *Boutelouas* of several species. Forbs present are *Stillingia sylvatica*, *Yucca spp.* with sand sage locally present.

Animals are not so numerous as in moist dune communities; influents being limited to terrapins and a few jackrabbits. Grasshoppers of various species probably exert more influence on the community than other animals normally present. Over-

grazing and trampling by cattle produce blowouts altogether similar to those described for moist dunes. Sand lodges amongst the bunch grass forming new dunes, which are barren and active for longer periods than moist dunes.

The first plant invaders to establish themselves are sandburs, *Cenchrus* sp. and *Stillingia sylvatica* (Text Fig. 3). The latter is disseminated by rodents gathering and storing the seeds, and plants appear on young dunes from roots of old plants buried beneath the advancing sand. Sandburs are annuals, but nevertheless form effective sand binders during the life of the initial plant community.

The community changes from initial to mid-seral rank by the appearance of sand sage, *Artemesia filifolia,* and yucca. These afford shelter for kangaroo rats which dig burrows beneath the roots. The seral picture from here on is somewhat obscured by coaction. Indications are that *Yucca-Hilaria-Buchloe-Bouteloua* sub-climax community would follow, with a mixed grass climax association in prospect.

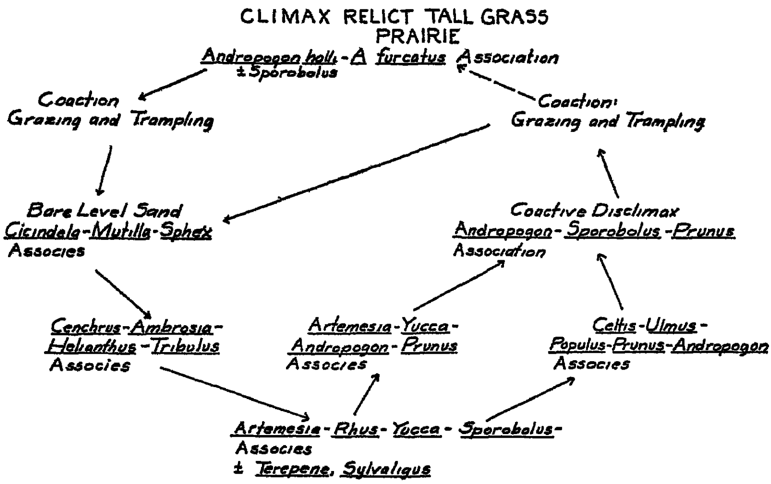
Intermittent grazing, however, has interfered with succession in all stages resulting in a jumbled array of blowouts and remnants of seral and climax communities alongside one another, which presents no valid picture. Plate 2, Fig. 1 shows a partly vegetated blowout. The vegetation is chiefly sandburs while the hummocks have held fast due to the presence of yucca and some bunch grass. Plate 2, Fig. 2 shows the effects of intense grazing and trampling near the base of a dry dune. Clumps of sage brush, together with some *Andropogon* persist on the hummocks.

In areas where grazing has not been so intense many dry dunes are covered by a disclimax community composed chiefly of *Hilaria* and *Buchloe,* with *Bouteloua, Sporobolus,* and the Andropogons occupying sub-dominant positions, or being only incidental. The inference is that succession would ultimately proceed to a mixed grass climax if grazing pressure were reduced (Text Fig. 3).

Succession on Level Sandy Areas. The areas of relatively level sand which occur within the dune belt are located for the most part where the ground water is quite close to the surface. These "flats" have originated in two ways: some are extensive blowouts, while others are apparently the result of aeolian deposition from older fluviatile deposits. In many places, blow-

outs have progressed even below the now present water table and shallow ponds have resulted.

Text Fig. 4 shows schematically how succession progresses on sandy areas. The initial community is an agglomeration of ragweed, *Ambrosia bidentata* and *A. artemesiafolia*, sunflowers, *Helianthus anuus* and *A. ciliatus*, sandburs, *Cenchrus* sp. and goatheads, *Tribulus terrestris*. All these species form local



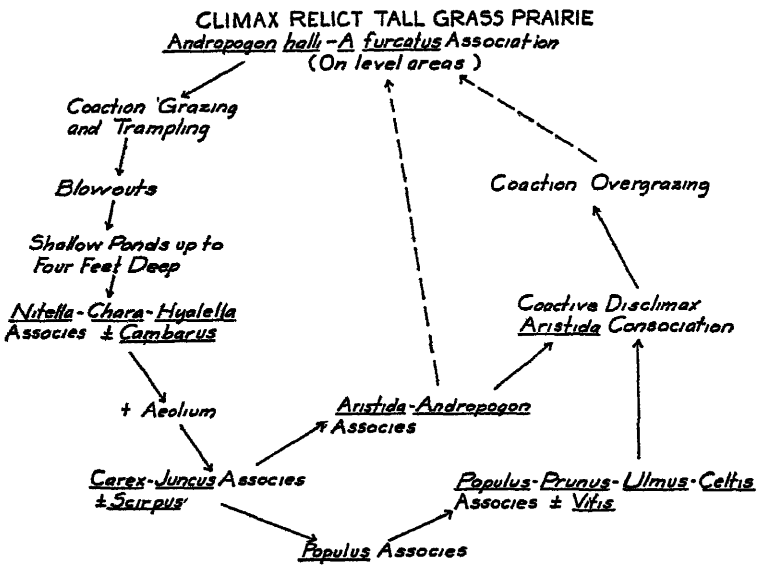
Text Fig 4 Succession on Level Sandy Areas

consocies depending primarily on the chance distribution of the dessemınules.

The initial community is replaced by an *Artemesia-Rhus-Yucca* associes, in which are considerable quantities of *Sporobolus ariodes and Panicum* spp. Clumps of sand plum occur locally. The next stage in succession is probably a development of the first mid-seral community, since sand sage is decidedly dominant, yucca is on the decline, sand plum is static or reproducing only slightly, and Andropogons have appeared in quantity.

If such areas were left undisturbed, they would in all probability return to the edaphic climax relict tall grass association, but under conditions imposed by present grazing programs, they are held rather static in the sage-sand plum-Andropogon stage. It can hardly be called a disclimax, since Andropogons, dominant in the relict climax, hold only a subdominant position.

In clumps of plum brush and local areas where the water table is at or near the surface, mots of elm, *Ulmus americana*, hackberry, *Celtis* sp., and cottonwoods, *Populus deltoides*, occur. Grape vines are often present in such places also, and the tangle produced furnishes excellent cover for skunks, cottontail rabbits, scaled and bob-white quail, and pack-rats. Swainson's and Sparrow hawks have been found nesting in the larger trees.



Text Fig. 5 Succession in Blowout Ponds

In all probability a slow advance is now in progress from both the sage-yucca-bluestem associes, and the hackberry-elm-cottonwood community toward a true climax of *Andropogon* and *Sporobolus*, with sand plum remaining in good sized clumps. At present, however, there are but moderate indications of this assumption (Text Fig. 4).

Ponds Formed by Blowouts. (Text Fig. 5.) As mentioned previously, blowouts frequently extend below the now present water table resulting in shallow ponds or lakes. The water varies from a few inches to about three feet in depth, and from a few square yards to two or three acres in surface area. During dry periods (minor cycles) the shallower ponds dry up owing to increased evaporation and lowering of the water table. The indications are that the deeper ponds have not gone dry

since their inception, and do not do so until obliterated by being filled with sand and vegetation.

The initial stage in the pond succession is a *Nitella* community, in which water beetles, amphipods, and crayfish may or may not be present. *Nitella* grows abundantly in the hard "gyp" water, and a deposit of so-called "chara coze"—black, foul smelling mud—is present in some of the deeper ponds. Many aquatic insects are associated with the *Nitella*, and *Hyallella knickerbockerii* is present in some ponds. Crayfish are present in ponds close to intermittent watercourses, since the animals are unable to migrate far overland.

Fringing the ponds and extending into shallow water for several feet is a Sedge associes composed chiefly of *Carex* and *Juncus*, and occasionally *Scirpus*. This community becomes extended centripetally as the depth of the water is reduced by accumulating sand. Associated with the Sedge community are the western leopard frog, *Rana sphenocephala*, the cricket frog, *Acris* sp., together with snails of several unidentified species. Cotton rats, *Sigmodon* sp., have well-worn trails in the dryer parts of the community. During the winter months, long billed marsh wrens were observed in the dead sedges.

The sedge community is succeeded by either of two associes, depending on the rate of deposition of sand in the ponds. If deposition is rapid, needle grass, *Aristida* spp. and the blue stems rapidly appear. If grazing is on a reduced scale or absent, *Andropogon halli*, and *A. furcatus* eliminate the *Aristida* and the relict climax of tall grass results. Grazing, however, often eliminates the tall grasses and results in the extensive stands of needle grass to the exclusion of all other plants. If the accumulation of sand is slow, cottonwood seedlings appear in the sedge community and form a transitory stage in succession. Many are quickly eliminated, leaving only an occasional tree to reach maturity. Sand plums follow next in order, followed by elm and hackberry seedlings. These in turn modify conditions so that grape seeds, scattered by birds resting in the developing trees, germinate and ultimately form a tangled mass of vines. The associes thus formed (*Prunus-Ulmus-Populus-Celtis-Vitis* associes) is probably sub-climax in rank, since no noticeable reproduction occurs.

There is sufficient moisture present owing to the high water table for trees to survive for considerable periods of time. The

inference is that the community would ultimately revert to tall grass prairie under natural conditions. Modified as it is by the presence of cattle which are limited in range by fences, blowouts are often started in the vicinity of clumps of trees. The beasts congregate in such places for shade and shelter, especially during the summer.

SUMMARY.

Geologically, the dunes of the area represent two or more stages of development as shown by the presence of both stationary and migratory types. This is also suggested by the variation in texture, color of the materials, and the abundance of heavy materials in the various dunes. The diameter range of the sand in the maximum size grade is smaller in stationary dunes and the color of the materials is darker (reddish brown), probably due to a greater abundance of iron coated sand grains. The heavy minerals are similar in each of the dune types but, with the exception of magnetite, are present in greater abundance (with respect to the per cent of the total number of sand grains) in migrating dunes.

No part of the sand dune belt confined chiefly to shallow, basin-like structures extends beyond the limits of the Tertiary and early Pleistocene deposits. These underlying sediments are at the present time undergoing erosion and redeposition. As a result of this gradational work, caliche fragments are found in many of the dunes. The heavy mineral suite of the Tertiary sands and the sand dune materials is similar also. Other sediments probably of lacustrine origin (with the exception of iron stained quartz grains) are similar to the materials in the sand dunes. This evidence suggests a local origin for the windblown sands.

The dune belt under discussion consists of five edaphic parts. These are: 1. moist dunes; 2. dry dunes; 3. level areas that have never been covered by sand; 4. level sandy areas, and 5. shallow ponds caused by wind action.

Some dunes are stable, others are semi-permanent, while others are young and actively migrating.

There has been an apparent rejuvenescence of dune activity within the past several decades. This has probably resulted from a combination of a progressively more arid climate since late Pleistocene times, and coaction initiated during the past several decades of overgrazing. Blowouts result from insuffici-

ent ground cover. These in turn have initiated both physiographic and ecologic succession (coseres of Clements) within the area. Each edaphic portion of the dune belt has its particular cosere. If the water table is high, the edaphic climax of moist dunes, level areas, and blowout ponds is a tall grass prairie community. If the water table is low, or is insulated from dunes by an intervening layer of caliche and a buried mature prairie soil, the climax association is a faciation of the bunch grass prairie, the climatic climax of the region. There is little or no evidence that the geologic age of the surface substratum correlates with the biotic communities thereon. Climate acting directly, and in concert with the characteristics of the substratum, are the controlling factors.

All portions of the sand dune area, whether controlled chiefly by climate or by edaphic factors, now support specific coactive disclimaxes, the result of overgrazing.

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VERTICAL DISTRIBUTION OF PELAGIC FORAMINIFERA.*

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ABSTRACT The importance of additional knowledge of the ecology of pelagic Foraminifera is stressed. Methods for quantitative collections and study of pelagic Foraminifera are discussed. Study of five serial plankton tows indicates that living Foraminifera are present in significant quantities down to a depth of at least 1,000 meters.

STUDY of submarine cores has shown the necessity of more accurate knowledge of the ecology of Foraminifera. The most fundamental problem is the question of where the animals live during all or part of their existence. It is known that certain species are pelagic, because they have been collected in plankton tows, and it is assumed that all others are benthonic.

Most geologists have subconsciously assumed that all pelagic Foraminifera live at the surface of the sea. This does not appear logical since other elements of the plankton live throughout the water column. It is true, however, that the greatest abundance of plankton occurs in the surface water layers. In addition, certain distributions of benthonic Foraminifera in submarine cores are difficult to explain if we assume that they are strictly benthonic.

There are other aspects of the problem of distribution of pelagic species. Do the shells in marine bottom samples represent an assemblage which lived in the water directly above the position of the sample? How far are the shells transported by currents before deposition? In interpreting past marine environments by faunas in submarine cores, it is essential to know what water layers are being interpreted. Most of the work done on submarine cores has been a study of the different marine environments represented by the deposits at different levels in many cores. The recognition of environmental differences in the sediments which occur in the cores is based almost entirely on different occurrences of Foraminifera at different stratigraphic levels. Most of the differences between faunas occurring at different core levels can be interpreted as due to

* Contribution No 338. Woods Hole Oceanographic Institution

water temperature or climatic variations. Many of the Foraminifera used for these relative temperature determinations are pelagic.

If all the pelagic forms normally live at or near the surface of the sea, the problem of interpretation is a simple one, but the greater the vertical distribution of the pelagic Foraminifera, the more complex the problem. In ocean water of warm tem-

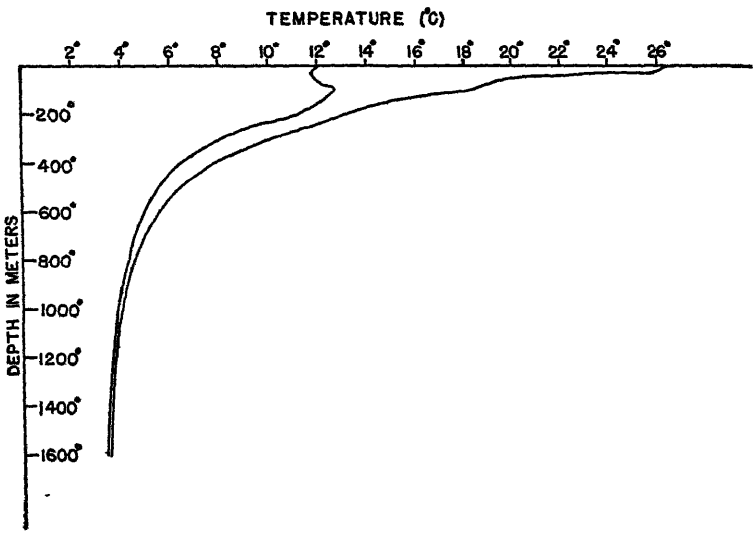

Fig. 1. Minimum and maximum temperature profiles for the continental slope water off eastern North American. (Modified after Iselin.)

perate regions there is a decrease in temperature with depth. Moreover, the layers of water above about 100 meters depth have a much greater annual range of temperature than deeper water. This is shown graphically in Fig. 1, which contains generalized minimum and maximum temperature curves for the water of the continental slope off eastern North America. Any foraminifer which lives at 500 meters depth must have a different temperature tolerance (8-10° C.) than one which is restricted to the surface (12-26° C.) (See Fig. 1).

This paper is in the nature of a report on methods which have been developed for attacking the problem of bathymetric distribution of Foraminifera. The data obtained from the plankton tows made by the writer are inadequate, but they illustrate the procedure and may be indicative of the type of results to be expected in future investigations.

Any study of the distribution of pelagic Foraminifera should

be made from tows taken at known water depths and should be quantitative if it is to be of any value in solving the problems relative to ecology and paleoecology. Most records of tows are purely qualitative and are from surface water zones. One of the recent exceptions is the work done aboard the *Meteor* in equatorial Atlantic waters, reported by Schott (1935).[1] A series of traverses were made between the African coast and Brazil. In the report of the Meteor Expedition, Schott lists plankton tow records for Foraminifera from 93 stations. The tows were made with a Nansen closing net, and the water was sampled at various depths down to 1000 meters. The tows were of uniform time duration and the total number of specimens of Foraminifera in each sample were counted, with percentage ratios of the species also listed. In this region the greatest frequency of pelagic Foraminifera is in water depths of 0 to 100 meters, although significant numbers occur at all depths sampled. The following is an analysis of Schott's data by the writer, and it clearly shows this.

Depth in Meters	No. of Tows	Mean No of Specimens per Tow
0–100	71	489
100–200	7	8
200–400	13	24
400–600	19	10
600–800	12	11
800–1000	19	28

Globigerinoides sacculifera is the most abundant species in the Atlantic equatorial region. *Globigerina bulloides* and *G. inflata* are found in abundance only in the colder surface waters of this equatorial region or in the colder water at considerable depth.

The quantitative results of these tows are only partially reliable, as Schott realized. The reliability of the results showing the mean numbers of specimens occurring at different depths is directly proportional to the number of tows. A difficulty inherent in the Nansen closing net is that the volume of water strained is unknown. Great variation in volume strained is common, as illustrated by quantitative plankton samplers now in use No attempt was made to discover which specimens were alive when collected and which were simply empty shells. The empty shells represent specimens which are sinking to the bottom and are of no significance in solving problems of habitat.

During a short cruise of the *Atlantis* in the summer of 1941, the writer made serial plankton tows at known depths to 1000

meters. These were made with the quantitative sampler developed by Dr. George L. Clarke and Mr. Dean F. Bumpus (1940)[2] of the Woods Hole Oceanographic Institution. This device may be opened and closed at known depths, and in addition, the volume of water strained is measured by the revolutions of a propeller. The plankton was preserved successfully in neutral formalin; adequate neutral formalin may be made by addition of sodium carbonate to the solution. Formalin which is not neutralized will, in many cases, dissolve the tests of Foraminifera. The use of alcohol as a preservative is not recommended since it makes a white gelatinous precipitate with sea water, and it is difficult to see and to disengage Foraminifera from the other plankton.

In operating these plankton nets for pelagic Foraminifera, certain precautions must be observed, since the small size and relative abundance of the specimens may cause inadvertent contamination from material on board ship or in water layers not being sampled. The nets must be kept in a clean container or hanging, and contact with other things on board avoided. When the nets are recovered after a tow has been made, they should be thoroughly washed on the outside with fresh water or filtered sea water. After recovering the plankton from the net, which is done by repeated washing into a bottle fastened to the end, the net should be cleaned with a stiff spray of water for several minutes.

In order to study the Foraminifera it is necessary to separate them from the remainder of the plankton, of which they may constitute only a fraction of one per cent. This may be done by extracting each specimen with a pipette, and this procedure avoids injury to delicate specimens. Each plankton sample must be thoroughly examined several times, since small specimens tend to be obscured by other plankton materials.

One of the difficulties has been to distinguish living specimens from empty tests. This involves recognition of protoplasm in the specimen and is very difficult without staining. Certain biological stains can be applied, but decalcification of the specimens is advisable and in most cases necessary. This procedure destroys the test which is most valuable for a paleontologist and upon which the recognition of the species is based. At the suggestion of Dr. George P. Child of the Amherst College Biology Department, a successful technique for recognizing protoplasm without dissolving the test was developed by Mr.

Garrish Metcalf, a student at Amherst College. This is the Biuret test for protein in which the protein-containing substance such as any protoplasm is colored purple.

The procedure in making the Biuret test on this material is as follows: Foraminifera in formalin solution are placed in a shallow glass evaporating dish and to this a few drops of a 10 per cent solution of sodium hydroxide are added. The sodium hydroxide breaks down the proteins in the protoplasm to form compounds related to urea. After several minutes (in the experience of the writer approximately 30 to 40 minutes) a few drops of a very dilute solution (.05 per cent) of copper sulphate is added. In a short time the protoplasm is colored purple and this coloration can be seen clearly through the test against a white background with a properly adjusted light source. If the specimens are to be stored for future reference, it is necessary to wash them several times before storing, since the sodium hydroxide eventually will destroy the tests. The entire technique is simple, speedy, and the shells can be preserved for future reference.

This method can be used to great advantage in studying benthonic populations. Any marine bottom sample probably contains more empty tests than live Foraminifera. It is necessary to know which specimens were living at the time the sample was taken to determine: 1.) which species actually live in that environment and were therefore not transported there, and 2.) the productivity of the area and therefore the probable rate of accumulation of the tests. Also, there is some evidence that certain pelagic species may live a part of their life cycle at or near the bottom. Many empty tests of Foraminifera become filled with clayey substances on marine bottoms. These materials have an appearance not unlike protoplasm after being placed in a preserving solution. Ordinary biological stains affect this substance in almost the same way as they do protoplasm, and so cannot be used to differentiate living from dead specimens. The Biuret test is a successful method for distinguishing those individuals filled with protoplasm.

The greatest concentration of pelagic specimens is in water over the continental slope and ocean basins, according to occurrences in bottom samples. The 1941 *Atlantis* tows came from the basin of the North Atlantic, south of Georges Bank, where the depth of water varies from about 3000 to 5000 meters. The tows were made primarily to discover if the

FIGURE 2. Distribution of Foraminifera in Plankton Tows.

	Station 1 Lat. 40° 05′ N Long 68° 21′ W			Station 2 Lat. 39° 50′ N Long 67° 11′ W			Station 3 Lat 40° 58′ N Long. 66° 39′ W		Station 4 Lat 40° 43′ N Long 69° 50′ W			Station 6 Lat. 39° 55′ N Long. 68° 48′ W		
	Sample 1 Depth 700 m. Vol 26 04 cu. m.	Sample 2 Depth 350 M. Vol. 12 58 cu. m.	Sample 3 Depth 70 m. Vol 6.13 cu m.	Sample 1 Depth 1000 m. Vol 5.14 cu m.	Sample 2 Depth 650 m Vol 11.92 cu. m.	Sample 3 Depth 400 m. Vol 4 91 cu. m	Sample 1 Depth 700 m. Vol 35 44 cu. m	Sample 2 Depth 325 m Vol. 20 6 cu. m.	Sample 1 Depth 975 m. Vol. 17 73 cu. m.	Sample 2 Depth 475 m. Vol. 17 61 cu. m.	Sample 3 Depth 75 m. Vol 17 51 cu m.	Sample 1 Depth 1000 m. Vol 28 36 cu. m.	Sample 2 Depth 500 m. Vol. 18 4 cu. m.	Sample 3 Depth 100 m. Vol. 19.84 cu. m.
Globigerina *bulloides*	1(*5*)	(*1*)	(*10*)	2(*2*)	(*11*)	9(*18*)	58(*70*)	(*8*)	72(*56*)	2	16(*13*)	12(*34*)	(*1*)	6(*1*)
G inflata				(*2*)		(*3*)	1							
G pachyderma									2					
Globigerinoides *rubra*	1(*3*)		5(*9*)	4(*4*)	(*11*)	4(*9*)	5(*8*)		8(8)		2	1(*7*)		1
G truncatulinoides				(*1*)	(*1*)		(*1*)							
Globigerinella *aequilateris*				(*2*)	(*1*)									
Unidentified Globigerinidae							8							
Globorotalia *scitula*						(*1*)		(*1*)						
G hirsuta						(*2*)								
Orbulina universa							1							

The numbers in light type indicate living specimens and the numbers in italics and in parentheses indicate empty tests.

quantitative samplers could be operated successfully at great depths and whether Foraminifera occurred at depths in this region and could be collected. An equally important purpose was to use the material for experiments in the technique of preservation and study.

Since only six serial tows were made (and the material in one tow was destroyed in the process of experimentation) the results have no quantitative significance. It is possible, however, to make several interesting and important observations on the data obtained. The most significant fact is that specimens of Foraminifera were present in every sample collected at several depths from 75 m to 1000 m. The number of living specimens found at 1000 m. varied from 1.5 specimens to 4.6 specimens per cu m. of water. At station 4, approximately four and one-half times the number of living specimens per unit volume of water were found at 975 m as were found at 75 m. It is true that most of the specimens found in most of the deep tows were empty tests, presumably those settling from the upper layer of water. The data suggest a larger population of living Foraminifera at about 1000 m. than at about 100 m. at some localities.

Nearly all the specimens in the tows are very small and without exception very thin shelled. This may have been due to the season of year at which collecting was done (August). In bottom samples from the same region a large percentage of the specimens are large and heavy-shelled. By far the greatest number of living and dead specimens were of *Globigerina bulloides* with *Globigerinoides rubra* occurring in significant numbers.

This is preliminary to a more extensive program of towing for pelagic Foraminifera which, it is hoped, can be undertaken as soon as conditions permit It is further hoped that other individuals and organizations will undertake similar studies, either in the North Atlantic or elsewhere, and that similar studies will be made on benthonic populations.

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PHYSICAL AXES OF REFERENCE AND GEOMETRICAL AXES OF REFERENCE FOR QUARTZ.

AUSTIN F. ROGERS.

ABSTRACT. Coordinate axes OX, OY, and OZ used in equations involving piezo-electric, elastic, and other physical properties of crystals may be called *physical axes of reference* These are orthogonal axes for hexagonal crystals as well as for crystals of the other crystal systems.

Coordinate axes of reference for designating crystal faces may be distinguished as *geometrical axes of reference.* For crystals of the hexagonal system the following sets of geometrical axes of reference (axial systems) have been employed:

$a_1 : a_2 : a_3 : c$; $a_1 \wedge a_2 = a_2 \wedge a_3 = 60°, a_1 \wedge c = 90°$ (Weiss)
$a_1 : a_2 : a_3 = 1$; $a_1 \wedge a_2 = a_2 \wedge a_3 = a_1 \wedge a_3 = \alpha$ (Miller)
$a_1 : a_2 : a_3 : c$; $a_1 \wedge a_2 = a_2 \wedge a_3 = 120°, a_1 \wedge c = 90°$ (Bravais)
$a : b : c = \sqrt{3 : 1} : c$; $a \wedge b = b \wedge c = a \wedge c = 90°$ (Schrauf)

Only in the case of the orthohexagonal axes of reference of Schrauf do the physical and geometrical axes of reference coincide but the orthohexagonal axes are not suitable for geometric axes of reference.

The Bravais axes of reference are to be preferred to the Miller axes since the unit cell of the space lattice of quartz is a hexagonal prism-pinakoid combination rather than a rhombohedron.

Although a left-handed axial system may be advantageous for physical axes of reference in dealing with left quartz, the same set of geometrical axes of reference should be used for both left and right quartz.

In drawing enantiomorphous pairs of crystals (either plans, elevations, or clinographic drawings) left-handed crystals may be rotated to the right (clockwise) instead of to the left (counter-clockwise) as ordinarily.

INTRODUCTION.

IN equations involving the piezo-electric and elastic properties of quartz an orthogonal set of coördinate axes of reference is used (1) (2). The optic axis is selected as the Z-axis; one of the three polar electric axes, which are axes of 2-fold symmetry (A_2), is taken as the X-axis, and a line mutually normal to the optic axis and to the particular electric axis chosen is made the Y-axis. The latter-mentioned direction has in recent years been called the mechanical axis. The accompanying drawing (Fig. 1) shows in plan and side elevation a typical quartz crystal (forms $m\{10\bar{1}0\}$, $r\{10\bar{1}1$, and $z\{01\bar{1}1\}$) with an oriented plate usually known as the X-cut since it is normal to an X-axis. It will be recalled that alternating voltage applied along the electric or X-axis of such a plate sets

up a vibration (expansion and contraction) parallel to the mechanical or Y-axis and conversely, stress applied in the direction of the mechanical axis produces an electric charge on the sides of the plate in the direction of the electric axis. The frequency of the electric charge is largely a function of the dimensions of the plate(3).

A set of coordinate axes such as X, Y, and Z[1] may be called *physical axes of reference* to distinguish them from coördinate

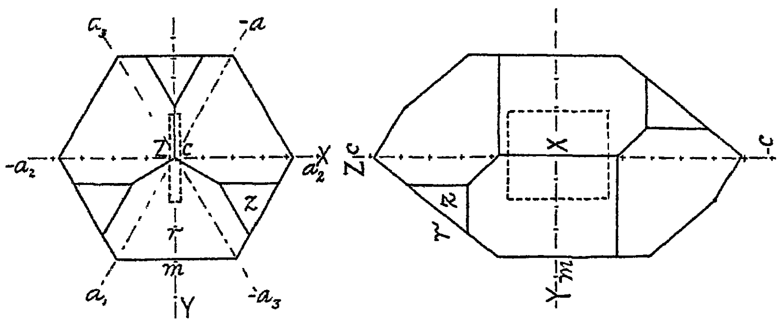


Fig. 1. Plan and side elevation of a typical quartz crystal with X-cut plate showing physical axes of reference X, Y, and Z and geometrical axes of reference, a_1, a_2, a_3, and c.

axes used in denoting the position of crystal faces which may be called *geometrical axes of reference*.[2]

In Fig. 1, the geometrical axes of reference of Bravais, a_1, a_2, a_3, and c are represented by dot-and-dash lines. The physical axes of reference X, Y, and Z are indicated by dash-with-vertical-dot lines. Where geometrical and physical axes of reference coincide as in the case of the c-axis and the X-axis a dash-with-cross-dot line is used. Orthogonal axes are always employed for physical axes of reference in all crystal systems.[3]

Crystal morphology is unusual in that a considerable variety of axes of reference are required. In the customary treatment

[1] If capital letters are used for these axes there need be no confusion with the lower-case letters x and z used in designating crystal faces and forms.

[2] The term "crystallographic axes" often used for axes of reference should be avoided since there are various other axes involved in geometrical crystallography such as axes of symmetry and zone-axes which are no less important.

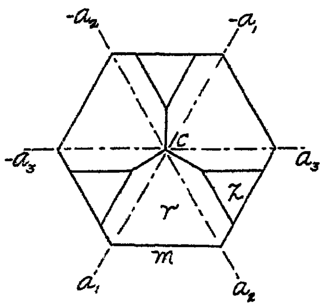
[3] These are usually given as OX, OY, and OZ as in analytic geometry, but Wooster(2) prefers OX_1, OX_2, and OX_3.

of geometrical crystallography these are almost taken for granted and there is not enough discussion of their variation. The *chief emphasis placed upon axes of reference has been* their use in defining crystal systems but entirely too much stress has been put on this relation. It seems better to define crystal systems in terms of zones (4, p. 38).

It is my purpose here to inquire into different sets of geometrical axes of reference, or axial systems[4] as Story-Maskelyne (5, p. 27) called them, used at various times for crystals of the hexagonal system which may be most simply defined as including all crystals with a single hexagonal zone (4, p. 39).

THE AXIAL SYSTEM OF WEISS.

Weiss(6), who shares with Mohs the honor of establishing the crystal systems in the early part of the nineteenth century, made use of four axes of reference, three in one plane (a_1, a_2, a_3) at angles of 60° to each other and a fourth (c) normal to the plane of the other three (see Fig. 2). At that period this



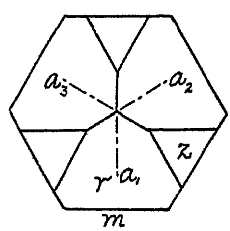


Fig. 2. Plan of a quartz crystal with the forms $r\{10\bar{1}1\}$, $z\{01\bar{1}1\}$, and $m\{10\bar{1}0\}$, showing the Weiss axes of reference.
Fig 3. Plan of a quartz crystal showing the Miller axes of reference.

must have been a bold suggestion but time has proved the wisdom of his proposal. He selected axes to suit the crystal rather than the reverse.

THE AXIAL SYSTEM OF MILLER.

Miller(7) adopted the method of indicating crystal faces by the index-symbols which bear his name, following the suggestion of Whewell(8), his predecessor at Cambridge, who is chiefly

[4] Axial systems, it should be remarked, have no necessary connection with crystal systems.

noted for his *History of the Inductive Sciences.* Instead of using four axes of reference for hexagonal crystals, Miller chose three axes parallel to the polar edges of a rhombohedron (see Fig. 3). Since these axes of reference are interchangeable they are designated as a_1, a_2, and a_3 and the interaxial angle α becomes the geometrical constant instead of the ratio $a:c$. Miller placed all hexagonal crystals in his rhombohedral system and did not recognize the hexagonal system even in his later work(9). For the general form of the dihexagonal dipyramidal class he used the double symbol $\{hkl\}$,$\{efg\}$. In spite of the fact that the indices h,k,l, and e,f,g are mathematically related, this feature is so objectionable that it has been abandoned for crystals of the hexagonal subsystem by practically all modern crystallographers.

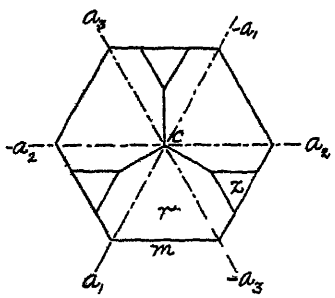
THE AXIAL SYSTEM OF BRAVAIS.

Bravais(10), who may be considered the founder of structural crystallography, remedied the difficulty of the double symbol necessary for some hexagonal crystals by using the four axes of reference of Weiss but took them in a different order. He placed the positive ends of the lateral axes a_1, a_2, and a_3 at angles of 120° (instead of 60°) as shown in Fig. 4. This furnishes the four-index symbol $\{hk\bar{i}l\}$ which is now known as the Bravais symbol. By selecting lateral axes at 120° instead of at 60°, crystals belonging to the rhombohedral subsystem (4, p. 75) which greatly predominate over those of the hexagonal subsystem (4, p. 75) are adequately treated. Bravais symbols are now much more extensively used than Miller symbols for crystals of the rhombohedral subsystem. Ungemach, Alsatian crystallographer, went so far as to express the opinion that the Miller three-index symbols should not be used for any crystals of the hexagonal system. This is an extreme view; it would seem preferable to employ Miller symbols in cases where the unit-cell of the space-lattice is a rhombohedron (Γ_{rh}) and Bravais symbols in cases where the unit-cell is a hexagonal prism-pinakoid (Γ_h) combination. This would mean the employment of both Bravais symbols and Miller symbols in the list of forms for the five classes of the rhombohedral subsystem as recommended by the writer (4, pp. 85-86) and now adopted in the new (seventh) edition of Dana's *System of Mineralogy.* The use of Miller indices brings out the relation of rhombohedral crystals to isometric crystals; this is often lost

sight of (4, p. 85). Miller indices may also be important in that they demonstrate that the faces of any crystal whatsoever may be represented by a three-index symbol.

THE AXIAL SYSTEM OF SCHRAUF.

Schrauf (12), one of the school of crystallographic physicists of Vienna, introduced orthogonal axes of reference for crystals of the hexagonal system. This he did by selecting one of the



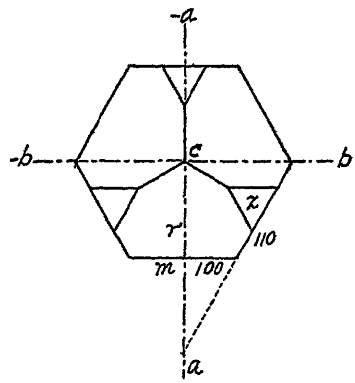


Fig. 4. Plan of a quartz crystal showing the Bravais axes of reference.
Fig. 5. Plan of a quartz crystal showing the Schrauf axes of reference.

three axes of 2-fold symmetry as the *b*-axis and a line normal to this axis and also normal to the vertical axis as the *a*-axis. The unit on the *b*-axis is 1 and the unit on the *a*-axis is $\sqrt{3}$ or 1.732. The *c*-axis is normal to both the *a*-axis and the *b*-axis. The axes of reference are shown on a plan view of a quartz crystal (Fig. 5). Schrauf's change of the name of the hexagonal system to orthohexagonal system is an interesting demonstration of the undue emphasis placed upon geometrical axes of reference in defining crystal systems.

In the Schrauf method the geometrical axes of reference coincide with the physical axes of reference and at first glance this may appear to be an advantage, but an insuperable objection is that a form such as the hexagonal prism (*m*) requires a double symbol {100}{110} as may be seen from Fig. 5. It is now generally agreed among crystallographers that any form must be represented by a single form-symbol and furthermore that all the face indices of a form must be permutations of one of the faces of the form. This, it will be recalled, was one of

the reasons for rejecting Miller's scheme of using three-index symbols for crystals of the hexagonal subsystem. Since the vertical axis in the hexagonal system is always either a three-fold or a six-fold axis of symmetry it is important that the lateral axes of reference should be symmetrically placed with respect to crystal faces which requires that either they or their

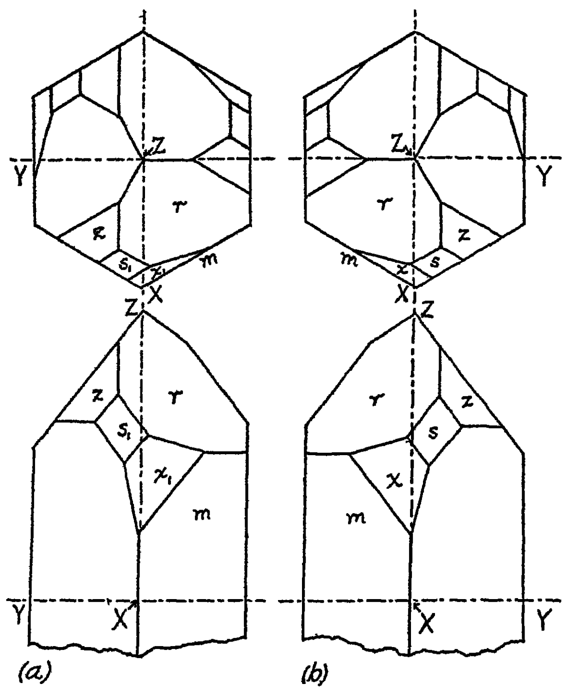


Fig. 6. (Modified from Cady and Van Dyke.) Plans and elevations of right quartz (b) (forms r $\{10\bar{1}1\}$, z $\{01\bar{1}1\}$, m $\{10\bar{1}0\}$, s $\{11\bar{2}1\}$, and x $\{51\bar{6}1\}$) and left quartz (a) (forms r $\{10\bar{1}\bar{1}\}$, z $\{01\bar{1}\bar{1}\}$, m $\{10\bar{1}0\}$, s_1 $\{2\bar{1}\bar{1}1\}$, and x_1 $\{6\bar{1}\bar{5}1\}$) showing the physical axes of reference, X, Y, and Z.

plan projections must be at angles of 60° and preferably at angles of 120° to each other.

The Schrauf method of treating crystals of the hexagonal system does not seem to be very well known, although he elaborates upon it in a book published not long after his article appeared(13). My first acquaintance with orthohexagonal axes of reference was a brief reference in a book by Bauerman (14) of the Royal School of Mines in London, an excellent text-book that came into my hands many years ago.

THE DRAWING OF ENANTIOMORPHOUS PAIRS OF CRYSTALS.

The inspiration for writing the present paper came from a perusal of an article by Cady and Van Dyke(15). In their paper they recommend the use of a right-handed axial system (physical axes of reference) for right quartz and a left-handed axial system for left quartz. Their proposal for what they call the *Right-Left axial system* is well illustrated by their Fig.

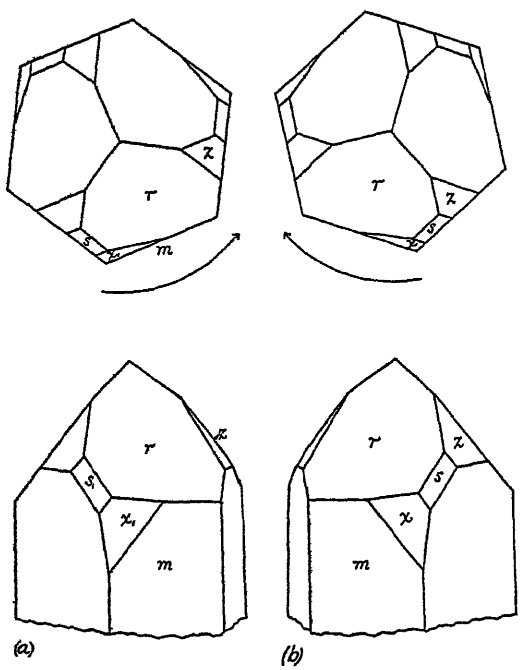


Fig 7. Plans and clinographic drawings of right quartz (b) and left quartz (a) drawn to bring out the enantiomorphous relation of the two crystals. (Forms as given in the caption of Fig. 6.)

2 which shows combined plans and elevations drawn so that the enantiomorphous relation of the two kinds of quartz is brought out. Fig. 6 of this paper is a simplification of their Fig. 2. It is evident that the two crystals so represented are mirror-images of each other.

In 1912 the writer(16) showed the enantiomorphous relation of right and left quartz by combined plans and clinographic drawings constructed so that the rotation of the left quartz is to the right (clockwise) instead of to the left (counter-clock-

wise) as ordinarily. The figure of the left quartz may be very simply made by tracing the drawing of the right quartz through from the opposite side of the drawing sheet. Fig. 7 is a new drawing of a right quartz crystal and a left quartz crystal made in this way.

THE REMARKABLE PROPERTIES OF QUARTZ.

The English author Robert Greene in his fantastic tale "Orpharion," written in 1588, in the passage ". . . as full of excellent qualities as the precious stone Silex is full of secret vertue . . ." *evidently refers to quartz or rock crystal.*

And now at the risk of being accused of *crystallolatry* I venture to call attention to some of the remarkable properties of quartz, which is the best known and one of the most important of all minerals.

(1) The optical activity or ability to rotate the plane of polarization, so prominent in quartz, is possessed by but one other mineral (cinnabar).

(2) The elastic properties may be represented by the figure of elasticity, a dimpled rhombohedron with much-rounded edges and corners (2, p. 250).

(3) The piezo-electric properties discovered by the French physicists, Jacques and Pierre Curie, in 1880, account for the use of untwinned quartz plates as frequency controls of radio transmitters. The piezo-electric surface is a triple-almond-shaped surface, the symmetry of the entire figure being that of the ditrigonal dipyramidal class (1, p. 863; 2, p. 216).

These and other physical properties are related to the vectorially discontinuous properties of form and solution.

The symmetry formula of α-quartz (low quartz) is $A_3.3A_2$. The axis of 3-fold symmetry is the optic axis and the axes of 2-fold symmetry which are polar are the electric axes.

The symmetry, not evident in a crystal such as represented in Figure 1, is manifest in some crystals by the presence of faces of the general form $\{hk\bar{i}l\}$ and $\{i\bar{k}\bar{h}l\}$, trigonal trapezohedrons, the most common of which are $x\{51\bar{6}1\}$ and $x_1\{6\bar{1}\bar{5}1\}$, or by faces of the trigonal dipyramid $\{h.h.\overline{2h}.l\}$ and $\{2h.\bar{h}.\bar{h}.l\}$, the most common of which are $s\{11\bar{2}1\}$ and $s_1\{2\bar{1}\bar{1}1\}$ (see Fig. 7).

The symmetry is also revealed by etching either euhedral crystals such as represented in Fig. 1, oriented plates, or cut spheres.

Quartz is truly one of the most remarkable of all substances. An adequate account of its properties will be found in the excellent monograph of Sosman(17).

In conclusion I wish to record my obligation to my colleague, Professor Stephen P. Timoshenko of the Mechanical Engineering department, a former student of Voigt at the University of Göttingen, who was good enough to discuss with me some of the points brought out in this article.

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SILICA IN NATURAL WATERS.

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ABSTRACT. The geological literature relating to the transportation and precipitation of dissolved silica is essentially unanimous as to the colloidal state of the silica.

The present paper reviews the geological literature with special reference to the basis for this conclusion It is shown that the conclusion is based on inadequate chemical evidence. Recent chemical investigations which indicate that the dissolved silica in natural waters is in true solution, probably ionic, are cited

As the prevailing theories on the origin of the siliceous sedimentary rocks are based on the assumption that the dissolved silica is colloidal, it is felt that knowledge of the overwhelming evidence to the contrary should clarify our geological thinking on these perplexing problems

INTRODUCTION.

DURING the past ten years the author has made rather extensive studies of chert in a variety of areas and geologic systems, but especially in the Mississippian limestone flanking the Ozark uplift. In attempting to arrive at a satisfactory explanation of field relationships I have found it necessary to examine the literature on the transportation of silica in natural waters. It has been found that there is a significant disagreement between the geologic and chemical literatures in regard to this subject. The present paper reviews each literature separately and presents what seem to be necessary conclusions.

The writer is indebted to numerous individuals, both geologists and chemists, who have discussed this matter with him. I wish to express my gratitude especially to Dr. F. B. Kniffen of Louisiana State University for his careful reading of the manuscript and to Dr. M. C. Schwartz, Director of the Engineering Experiment Station, Louisiana State University, for valuable assistance in the study of chemical literature and for his critical reading of the manuscript.

GEOLOGIC LITERATURE.

The geologic literature dealing with the transport of silica in natural waters considers the silica to be in a colloidal state. This concept has had profound effect on geologic thought regarding the origin of siliceous rocks.

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Nearly all subsequent discussions of the state of silica refer to a paper by Kahlenberg and Lincoln (1898)[11] * who remarked that their experiments seemed to indicate that silica in natural waters is colloidal. They examined the electrical conductivity and the effect on the freezing point of solutions of sodium, potassium, lithium, rubidium, and caesium silicates. These solutions were prepared by adding the required amounts of the pure alkali hydroxide to a solution of silicic acid. It was found that the alkaline silicate solutions thus formed were hydrolyzed into alkali hydroxides and colloidal silica. Calculations indicated that in a solution with less than one gram molecular weight of the silicate in 48 liters of water (1250 parts SiO_2 per million) the silica would be colloidal. After completing their chemical experiments, Kahlenberg and Lincoln found evidence in the literature that most natural waters contain very small amounts of dissolved silica. They therefore concluded without making a single analysis of natural waters that since the silica in the dilute solutions they had studied seemed to be colloidal, the silica in the even more dilute solutions (5 to 30 parts SiO_2 per million) in nature must also be colloidal.

This conclusion has been offered as sufficient proof of the colloidal state of silica in natural waters or as corroborative evidence to that effect by nearly every geologic author on the subject since 1900.

Clarke (1908, pp. 151-152)[3] makes the following statement: "In solution, according to L. Kahlenberg and A. T. Lincoln, sodium metasilicate is hydrolyzed into colloidal silica and sodium hydroxide; and this conclusion was also reached by F. Kohlrausch about five years earlier, although he stated it in a more tentative form. *In natural waters, then, silica is actually present in the colloidal state and not in acid ions.*" (Italics mine.) The same words are used in subsequent editions of the book in 1911, 1916, 1920, and 1924.[3]

Tarr (1917, p. 433)[22] accepts the idea that the silica in solution in streams is colloidal but does not refer to any supporting literature.

Van Tuyl (1918, p. 456)[29] comments that there may always be some dispute regarding the source of silica in chert but concludes ". . . that much, if not all, of the silica is of inorganic origin, having been deposited in the colloidal condition. . . ."

* Complete references will be found at the end of this paper.

Gruner (1922, p. 442)[8] states· "It was formerly believed that silica was carried in solution as alkaline silicate and that on separation from the alkali the silica was precipitated,* but it is now held that silicates are hydrolyzed and that silica is carried as a colloid in dilute natural waters."* The asterisks indicate the locations of foot-note references. The first reference is to a paper published in 1913, the second to the paper by Kahlenberg and Lincoln[11] published in 1898.

Lovering (1923, p. 534)[15] says "So far as is known, silica is transported only in the colloidal state in natural solutions. . . ." He gives a footnote reference to the paper by Kahlenberg and Lincoln.[11]

Tarr (1926, p. 25)[23] "It has long been held by Kahlenberg and Lincoln,[11] Van Hise,[28] Leith and Mead,[14] and others that the silica was liberated (during weathering) as a definite silicic acid, but the view held at present is that it exists in solution as a silica sol, containing a varying quantity of water." Tarr is here more concerned with the true character of the colloidal silica than with the colloidal or non-colloidal state of the silica.

Moore and Maynard (1929, p. 302)[17] accept the conclusions of Kahlenberg and Lincoln and give the results of similar experiments, concluding ". . . complete hydrolysis of sodium silicate does not take place until a dilution of at least 25 parts per million silica is reached. . . ."

"It would appear, therefore, that silica in solution in natural waters is transported as a true colloid provided the concentration does not exceed 25 parts per million. . . ."

Twenhofel (1932, p. 44)[27] refers to the paper by Kahlenberg and Lincoln and concludes "It is probable, moreover, that the silicon dioxide indicated by analyses of the solid matter in solution in natural waters is really in the colloidal state and not in true solution." On page 510 he considers the matter at somewhat greater length, citing additional references including Moore and Maynard and concludes ". . . essentially all of the silica in natural waters may be considered to be in the colloidal state."

Tarr and Twenhofel (1932, p. 526)[24] accept the colloidal state of the silica transported in natural waters and consider the character of the colloid.

The foregoing review is not exhaustive. It does not include references to all authors who have accepted the colloidal state

of the silica in natural waters, nor does it include references to authors who have preferred sources of silica other than surface or near surface natural waters. It is considered to be representative of American geological opinion regarding the state of silica in natural waters and probably also of British opinion.

CHEMICAL LITERATURE.

Chemical investigators have studied silica in solution rather extensively since the paper by Kahlenberg and Lincoln.[11] In general their investigations have been concerned with three major aspects of the problem.

1. The physical chemistry of alkali-silica-water systems.
2. The determination of silica in natural waters.
3. The removal of dissolved silica from natural waters in water purification, especially for boiler-feed purposes.

The study by Kahlenberg and Lincoln belongs in the first group. A more exhaustive investigation of the same type is found in a series of papers by Harman (1925-1926-1927)[9] on the system Na_2O-SiO_2-H_2O. As his conclusions are quite contrary to those of Kahlenberg and Lincoln they are presented here in some detail.

Harman investigated the conductivity, transport numbers, hydrolysis, sodium ion concentration, lowering of vapor pressure and freezing point, and heterogeneous equilibria in the system Na_2O-SiO_2-H_2O at 25° C. He studied the Na_2O-SiO_2 in ratios 2:1, 1:1, 1:1.5, 1:2, 1:3, and 1:4 at concentrations of 2Nw to 0.005 Nw.

Conductivity measurements showed that ratios 2:1 and 1:1 are excellent conductors, whereas ratios 1:2, 1:3, and 1:4 are good conductors in dilute solutions but abnormally poor conductors in concentrated solutions. Harman indicated that hydrolysis into NaOH and colloidal silicic acid is not sufficient to account for the conductivity. Assuming the silicate ion SiO_3^{--} to be present, he calculated its mobility from the conductivity results. Later experiments on transport numbers checked this calculation and showed that ratio 1:1 ionizes to Na^+, OH^-, and SiO_3^{--}. In ratios 1:2, 1:3, and 1:4 the concentration of silicate ions is high but each ion contains more than 1 (SiO_2) per divalent charge, the average number of mols SiO_2 per divalent charge being equal to the ratio. In ratios 1:2, 1:3, and 1:4 the silicate ion is not simple SiO_3^{--} but is

either an aggregation of simple silicate ions with or without colloidal silica or is a definite complex silicate ion.

Harman concluded from his freezing-point experiments that ratio 1 : 1 is the salt Na_2SiO_3 undergoing both hydrolytic and ionic dissociation. This process gives rise to the ions Na^+, OH^-, and SiO_3^{--} with some H_2SiO_3, the latter being crystalloid. Na_2SiO_3 is almost completely dissociated in dilute solution but only 27.8 per cent of it hydrolytically. Ratio 1 : 2 is the definite salt $NaHSiO_3$ behaving like Na_2SiO_3 and giving rise to Na^+, OH^-, $HSiO_3^-$ ions and crystalloid H_2SiO_3. Ratios 1 : 3 and 1 : 4 seem to be much more complex.

Harman concluded that SiO_3^{--} ions exist in all ratios up to 1 : 4. In ratios 1 : 1 and 1 : 2 the silica is all crystalloid in dilute solutions and in ratios 1 : 3 and 1 : 4 increasing percentages are colloidal. However, his conclusion which seems to have the greatest bearing here is that in extremely dilute solutions (0.005Nw) all of the silica in all ratios is crystalloid. Since 0.005 Nw, Harman's most dilute solution, is equivalent to 3.2 parts per million SiO_2 (Na_2O-SiO_2) which is of the same magnitude as the average content of natural waters, his conclusions would indicate that the silica in streams should be crystalloid, not colloidal.

Harman discussed in his fourth paper the results of Kahlenberg and Lincoln as well as those of other writers who favor colloidal silica and indicated fundamental errors in their assumptions and conclusions.

There is an extensive literature on the determination of silica in natural waters. Of particular interest here are papers relating to the colorimetric method and its response to colloidal and non-colloidal or crystalloid silica.

The colorimetric determination of silica seems to have been proposed by Jolles and Neurath (1898),[10] although it is commonly credited to Dienert and Wandenbulcke (1923).[6] See comprehensive, annotated bibliography in Schwartz (1938).[20]

Dienert and Wandenbulcke[6] describe the method and present results of the analyses of river waters. The test is made by adding 4 drops 1 · 4 H_2SO_4 to 50 cc. of water to be tested and then adding 2 cc. of 10 per cent solution of ammonium molybdate which produces a yellow color due to the formation of a complex silico-molybdate. This yellow color is compared with

that of standard solutions to reveal the amount of silica present. Note: There have been numerous modifications of the method proposed because of interferences, etc., but the essential principles remain the same.

According to Dienert and Wandenbulcke, the importance of this test lies in the fact that it will not determine colloidal silica. It reacts only to silica in true solution. The authors explained that any colloidal silica present can be destroyed by adding .2 g $NaHCO_3$ per 50 cc. and heating on a water bath. They found, however, in their study of river waters that there was no detectable colloidal silica present.

In a later paper, Dienert and Wandenbulcke (1924),[7] describe the effects of alkaline solutions on colloidal silica. Their experiments indicate that in a two per cent sea-salt solution containing 120 milligrams of colloidal silica per liter, 88 mg. of non-colloidal silica is formed in seven days at 37° C., complete conversion occurs in six days at 41° C. or in two hours at 90° C. They point out, furthermore, that all neutral or alkaline solutions will act the same, whereas acid ones prevent conversion. They conclude from these experiments that the silica in natural waters is almost exclusively non-colloidal because alkaline salts dissolved in the water would convert any colloidal silica to the non-colloidal form.

Although the temperatures at which the experiments were conducted are somewhat above the temperatures of natural waters, time seems to be an equally important factor.

Harman (1927)[9] in the last of the seven papers already referred to discusses the colorimetric method. He used the method to analyse some of his solutions, and states that it will not determine colloidal silica.

The colorimetric method has been and is now widely used by biochemists and industrial chemists for the determination of silica in natural waters. Examination of their results shows that the quantities of silica indicated colorimetrically agree closely with those indicated by gravimetric methods. Many authors state that the colorimetric method will determine only silica in true solution or silica that is in the crystalloid state, although in more recent papers they seem to assume that there is no longer any question of this.

Industrial chemists who have investigated ways and means of removing dissolved silica from boiler feed water are unani-

mous that the silica is not colloidal. Schwartz (1938, p. 551)[21] reviewing this literature states: "Those investigators who have considered the problem experimentally have established the fact that silica can be, and is, present in the crystalloid state. Unpublished results obtained by the author with Mississippi River water at Baton Rouge, La., corroborate this finding. . . ."

Schwartz (personal communication, but see also bibliography 1934,[19] 1938,[20] and 1938[21]), investigating the silica content of the Mississippi River at Baton Rouge, Louisiana, made the following comparisons· first, water clarified and silica determined colorimetrically and gravimetrically; second, water clarified, ultrafiltered and silica determined by both methods. In neither instance was there any difference in the indicated silica content. The silica content of the Mississippi as determined by Schwartz (1938, p. 554)[21] is about seven parts per million, rarely varying more than two parts per million. This checks closely with earlier gravimetric analyses at New Orleans (11 parts per million) and Carrollon, La. (7 parts per million) reported by Clarke (1924, p. 80).[3]

Other quantitative studies using the colorimetric method may be found in papers by Atkins,[1] Lucas,[16] Thompson and Johnson,[25] Hazel King,[13] Earl King,[12] and Cooper.[5] In every case the results are comparable with average gravimetric analyses for the same or similar waters.

The author has found only one paper which questions the qualitative significance of the colorimetric method, Tourky and Bangham (1936).[26] Their results, however, are not sufficient to vitiate those of the authors already referred to.

Another indication that silica in natural waters is not colloidal has been presented by Rees.[18] He discussed the analysis of waters used in boilers by which the sodium and potassium were determined by difference and reported as sodium. Positive ions Ca, Mg, and NH_4 were determined, calculated into mille equivalents and totalled. Negative ions SO_4, NO_3, Cl, and CO_3 were treated likewise. The difference gave the amount of Na and K present. In some waters it was found that the positive ions were higher than the negative ions, a fact which suggested that some negative ion was present and not considered. The silica in the water determined colorimetrically and calculated as negative ions gave a sodium value by difference which checked very closely with the analytical value for sodium. In contrast

to this is the conclusion of the chemists of the Water Resources Branch of the United States Geological Survey as stated by Collins, Lamar, and Lohr (1932, pp. 5-6).[4] "Its (silica) state in natural waters is not definitely known, but in reports of analyses it is assumed to be in the colloidal state, taking no part in the equilibrium between the acids and bases." This conclusion was stated again in almost the same words in a letter to the author by W. W. Hastings, chemist in the Survey laboratory at Austin, Texas, dated February 14, 1944.

SUMMARY.

The prevailing view on the part of geologists, that silica in natural waters is in a colloidal state, is based mainly on the work of Kahlenberg and Lincoln.[11] If, however, we are to extrapolate from experiments with alkali silicate solutions to conditions existing in natural waters, it is obvious that Harman's results,[9] based as they are on more elaborate and complete experiments, are more reliable than those of Kahlenberg and Lincoln. The results obtained by Harman indicate that the silica in natural waters is in solution as the silicate ion SiO_3^{--}.

The colorimetric method for the determination of silica, which has been shown by many authors to react only to silica in true solution, shows directly that the silica in natural waters is not colloidal. The close check between colorimetric and gravimetric values for silica in natural waters eliminates the possibility that only a part of the silica is ionized and detectable by the colorimetric method.

Additional chemical studies, such as the one by Rees[18] referred to above, further substantiate the view that the silica in natural waters is in ionic solution.

The experiments of Dienert and Wandenbulcke[7] seem to indicate that any colloidal silica present would in time become crystalloid because natural waters are prevailingly alkaline.

The ultimate distinctions between true solution and the colloidal state are the molecular size and atomic structure of the individual particles, and the chemical behavior of the substance in solution. In both regards, the available chemical literature indicates that the silica in natural waters is in true solution.

The character of the crystalloid silica particles in natural waters is not definitely known. Harman's experiments on elec-

trical conductivity, ion mobility, and transport numbers indicate that there are a number of possible silicate ions. In the dilute sodium silicate solutions with Na_2O-SiO_2 in the ratio 1 : 1 Harman[9] concluded that all of the silica was in the form of the ion SiO_3^{--} and this, indirectly, favors a similar conclusion with regard to the silica in natural waters. Rees[18] assumed the ion SiO_3^{--} to be present and succeeded in balancing the acids and bases satisfactorily; however, another divalent silicate ion might have served as well. The solubility of silica in natural waters seems to be very sensitive to the pH value (Cooper, 1933).[5] It is likely that the nature of the ion is also affected by the pH value and will not be the same in all natural waters or remain the same in a given water which undergoes changes in pH value.

The desirability of additional research with respect to the actual molecular character of the dissolved silica and the ways in which the silica may be precipitated is obvious. To be of geologic significance, such research must be concerned directly with the silica in natural waters. The difficulties to be met in such investigations are also obvious. First, the extremely low concentrations of silica in solutions containing greater concentrations of more active ions. Second, the studies on precipitation must attempt to simulate the geologic environments in which the siliceous rocks are known to have formed. Some evidence relative to the precipitation of the silica can undoubtedly be found by the geologist in the field if he is not handicapped by preconceived notions about the state of the silica in natural waters or about the methods of its precipitation. The third, and perhaps the greatest difficulty, is that the geologist does not have the equipment, training, or the inclination to undertake such studies and the chemists are not sufficiently concerned with these matters.

CONCLUSIONS.

Chemical investigations, approaching the problem in a variety of ways, do not support the widely accepted concept that the dissolved silica in natural waters is colloidal. On the contrary, these investigations, to date, justify the following conclusions:

1. The dissolved silica in natural waters is in true solution or crystalloid rather than colloidal.

2. Although the molecular character of the dissolved silica has not been investigated directly, the evidence indicates that it is ionic.

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DISCUSSION.

FURTHER REMARKS ON CONTINENTAL DRIFT.

Absence on service has prevented Dr. G. G. Simpson from making answer to the writer's rejoinder (2 b), but in the meantime three other criticisms of the hypothesis have appeared in this Journal. The two by Dr. C. R. Longwell[1] (5 a, 5 b) express doubt together with a reproof to supporters of the idea for not taking up a sufficiently objective attitude; the other by Dr. Bailey Willis (7) voices frank disbelief, with the request that the hypothesis be liquidated. In general their, as well as others', criticisms can be grouped under five heads:—a) the attitude of those favoring drift, b) the interpretation of the detailed evidence cited therefor, c) former polar positions, d) the value of geodetic measurements and e) the physical possibility of such movement.

a) *Attitude.*

Longwell's protest in regard to insufficient objectivity will, so far as the writer is concerned, be conceded. Nevertheless the differences between the doctrines of "fixed" and "moving" continents are fundamental and the acceptance of the one must largely exclude the other (2 a, p. 3). My attitude, however, is that synthesis has advanced sufficiently to justify the rejection of the current idea of fixed continents and all the principles that go therewith. Consequently there would seem no particular gain in taking up a neutral or waiting attitude; the Wegener Hypothesis—or some variant thereof—must be either rejected or supported, and in so doing one's viewpoint is bound to become colored by the decision taken.

b) *Interpretation of Evidence.*

There is admittedly much that the protagonists cannot yet explain, the "Dogwoods" cited by Longwell (5 a, p. 224) being a case in point, though this problem forms a parallel to the puzzle of the late Cretaceous dinosaur-migration from East Asia to North America, as pointed out by Gregory. They are also accused of omitting evidence which is or might be of an adverse character. The writer has, however, drawn attention to a number of such cases, for example the absence of Triassic volcanics in Great Britain, in contrast with the eastern corner of North America.

[1] The author evidently had not yet seen Longwell's two latest notes on this hypothesis; one of which appeared in Science (N. S.), vol. 100, pp. 403-404, and the other in the Amer Jour. Science, vol. 242, p. 624.
—*Editor.*

Rather than spread discussion, attention may be focussed on the crucial case of the continents of Africa and South America. Imagine those masses reassembled, as Wegener has done, but with the Atlantic replaced by a long sinuous belt of Pleistocene deposits ranging up to a few hundred miles wide. With the numerous congruences detailed elsewhere (2 a, pp. 106-116) would there be much hesitation in presuming continuity of formation, structure, etc., beneath that Pleistocene covering, the more so that further work has brought out equally remarkable agreements for the Amazon and West African regions? Choubert's reconstruction (1) for the Atlantic border regions is not less compelling. Such congruences furthermore run oblique as well as transverse to the opposed shorelines. Nevertheless, with the ocean in between, these outstanding similarities have under normal views to be dismissed as mere coincidence!

Only through such reassembly can one perceive a unity of continental plan, not only in the gross, but in the detail, which in turn enables the hypothesis to be tested out in the field. Such deduction finds verification in the work of Leinz (4, p. 32) on the late palaeozoic glacials of Brazil through the discovery beneath the dominant green or blue tillite of an earlier red tillite in Paraná showing a more southerly direction of ice-flow, precisely as was recorded long ago for South West Africa, diagonally opposite. The chance arrival of Bol. No. 30 of the Instituto Geologico del Uruguay brings notice of a N. 30-40° E. strike for the ancient sediments west of Montevideo, which in a reassembly will run parallel to the corresponding strata of the south-west Cape. Is such just accidental?

It was through such replacement that a possibilty emerged of charnockites being present in the eastern part of the Union of South Africa, confirmed by their discovery in Natal, thereby bringing that region into alignment with Madagascar, Antarctica and India, and the same principles and methods are applicable to the other lands. The mathematical chances against such almost identical evolution being independent in these far separated lands becomes increased by each new point of agreement, and are already in the writer's opinion numerically opposed to fixed continents.

c) *Polar Positions.*

Few apparently, apart from Wegener, have troubled to study the evidence of *past climatic girdles* as deduced from the particular sedimentary facies around the Earth, though that constitutes one of the most important of criteria for Drift. Such, however, involves much searching through voluminous literature for the basic facts. More direct is "polar environment" as indicated by the

presence of ancient tillites. Now, represented in Africa are at least ten such glacial formations (of which a few could well prove equivalent), some with wide distribution. Either geologists are suffering from delusions when interpreting those formations or else the Pole of those times wandered somewhere in or near that continent, and I am still conservative enough to reject the first explanation. With fixed continents or poles Palaeoclimatology just does not make sense.

d). *Geodetic Measurements.*

In regard to the supposed changes in Longitude or Latitude of certain spots during the past few decades one must admit Longwell's contention (5 a, p. 228) that too much has been made of data that are admittedly imperfect and not always consistent, and also with Holland's recent pronouncement (3, p. 118) that such astronomical figures could scarcely be used to prove drift during the Mesozoic. Although the computed differences have come in for strong criticism, they cannot all be dismissed as due to errors of observation; Stetson's impartial review (6) brings that out, while the case of the Sydney Observatory (2 a, p. 300) should not be overlooked.

If, within periods that are infinitesimal, geologically speaking, measurable horizontal displacements of points on the Earth's surface have been proved or else seem probable, how can the relative or absolute fixity of continents during even a single geological epoch be taken as assured?

e). *Physical Possibility of Drift.*

Dr. Willis, like the majority, rejects drift on mechanical grounds. But do the simplified dynamics of rigid bodies favored by him apply inexorably to "living evolving continents" with circulatory systems evinced by perpetual transfers of materials horizontally or vertically, by changes in size, shape, internal and external stress, flotation height, internal temperature, etc., and not always gradually, but often rhythmically? Why indeed should their crumpling edges be assumed to offer enormous resistance to movement? What degree of opposition is met when a red-hot poker is pushed into pitch or solder? Again, why should a fracture in the rear of a moving continent produce an equivalent vacuum? How comes the supposedly tough crust to have been so readily diked, and whence originated the forces that have repeatedly snapped it in such diking?

Holland (3, p. 118) has indeed pointed out the fallacy of assuming that sub-crustal conditions identical with those of today must necessarily have existed during late Mesozoic-Tertiary times when world-wide diastrophic movements were in progress.

So far from "begging the question," as Willis asserts (7, p. 510), the writer has discussed at length (2 a, Chap. XVII) various factors that would or could have contributed to Drift. Too much has been made of the impossibility of sliding because adequate forces have not yet been disclosed by mathematical analysis. All such calculations have been based on assumptions that, considering the complexity of the problem, are regrettably limited in number and in certain cases extremely doubtful. For example, the importance of paramorphic transformations within the sub-crust—characterized by changes of volume without changes of chemical composition—continues to be overlooked This *Paramorphic Zone,* it is felt, can be regarded as the most likely section of the crust within which horizontal sliding of the kind envisaged during Drift could take place, more particularly during conditions of unloading, when the reactions within it would have tended to be exothermic. Such would moreover *lie above the Sima and therefore at a shallower depth* than that presumed by Wegener and others.

The thermodynamic rather than the dynamic nature of the problem must be stressed. Colossal amounts of energy must be absorbed or released in sub-crustal processes such as melting, crystallization, paramorphism, radioactive transformation, orogenesis, volcanism, etc., all acting in various fashions within a highly heated, heterogeneous and rotating Earth, subject to tidal stresses and other disturbances. Can it therefore be seriously declared that the crust could not have crept? Despite the foregoing it is frankly recognized that, until some more convincing physical explanation has been arrived at by geophysicists, no general acceptance of the Hypothesis can be expected, though such need not hinder the accumulating of other factual evidence.

Longwell (5 a, p. 230) has severely criticized the writer's statement that a continental block moving polewards, into an area of converging meridians, would experience an east-west compression, and, conversely, into an area of diverging meridians, an east-west tension. It should have been made clearer originally (2 a, p. 305) that such would have resulted not through meridian convergence or divergence, but through the variation in the Earth's peripheral velocity with change in latitude. The equations of motion (Blount) show that displacement changes must be produced in the accelerations of all parts of the block due to the Earth's rotation, which would not only tend to twist the block (clockwise if moving towards the North Pole), but to develop an east-west compression, greatest in the leading edge, and a counterclockwise twist and an east-west tension if the drift were equatorwards, the block being viewed as a non-rigid body. Such accelerations become greater towards the poles and, although small, are cumulative.

In addition any currents in the sub-crust must—like the winds—be similarly deviated, thereby *aiding* in rotating and deforming the overlying drifting blocks, particularly during periods of sub-crustal melting. Once a tendency has been established, it could be intensified by other influences.

Conclusions.

With the continents at their present distances apart geologists will have little of definite character to submit concerning unknown portions, whereas the much criticized Hypothesis of Continental Drift will commonly have something suggestive to offer, and even prediction in special cases.

Like other hypotheses it is to be judged not only by the state of knowledge when it was formulated, but by subsequent findings coupled with the preceding implications. Those who oppose it, venturing little in that respect, have on the contrary nothing to lose through such discoveries. It is all the more encouraging therefore to record that the flood of fresh literature, particularly concerning the outposts of the Earth, continues to bring forth so much new evidence, which when not providing positive support, is usually not adverse thereto. As contrasted with the static outlook engendered by Fixed Continents, the doctrine of Moving Continents continues to prove dynamic and fertile in every field.

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CHEMISTRY.

Introductory General Chemistry; by STUART R BRINKLEY. Pp. x, 615; 235 figs., New York, 1945 (The Macmillan Co., $4.00).—The third edition of Professor Brinkley's excellent text is a thorough revision of its predecessor (1938), with improved and modernized treatment of many topics. The page number is somewhat smaller, but new material has actually been added without sacrifice of any important topics previously included. The use of narrower margins and omission of portraits and industrial photographs made this possible. The number of chapters has been decreased to thirty-five, as compared with forty in the second edition, by the consolidation of related topics and improved organization The useful list of problem exercises at the end of the book has been greatly expanded, and the appendix includes new data, such as a table of ionization constants of many weak acids, which was lacking in the second edition. The index is unusually complete and accurate, an essential requirement of a good text.

The most pleasing quality of this text is the scholarly approach to all topics. A reader of Brinkley is not given the intellectual insult of being asked to swallow assertions of theory without proof, because the author carefully sets forth the experimental evidence and methods by which it is obtained, and on this foundation constructs for the student the great theories of science. The reviewer, however, does wish that the author had presented a more extended examination of the massive outlines of the logic leading to the atomic theory and the knowledge of chemical formulas. Professor Brinkley avoids the mistake made by most authors of elementary chemistry texts in their introductory chapters, by which the student finds himself reading chemical formulas without knowing whence they came, but he could have avoided it by a wider margin. For example, it is not made perfectly clear why the formula of water is H_2O and not HO. Chemists as late as 1854 thought water was HO, and were consequently in error in their formulas for all compounds containing oxygen and hydrogen, because they had failed to appreciate the importance of Gay-Lussac's Law of Combining Volumes and Avogadro's Hypothesis. Some authors also tend to avoid or skirt the edge of difficult topics, but in this text the attack on such topics is direct and skillful with such clarity that over-simplification is unnecessary. As a result, the student does not

have anything to unlearn before extending his knowledge of the science.

An example of the logical organization and grouping of related topics is the section including Chapters 10-13 inclusive. Here the pertinent chemistry of the alkali metals and the halogens is used as the experimental basis for presentation of the periodic system, followed in turn by an excellent chapter on atomic structure. Following this is another logical group, beginning with ionization and continuing with several chapters on the various kinds of ionic reactions, including electric cells, ionic reactions involving solubility products and ionization constants, analytical chemistry, and oxidation-reduction in solution. The treatment of acids and bases is according to Bronsted's ideas and is well done. The presentation of oxidation-reduction is particularly good, with adequate emphasis on the electronic half-reactions. The reviewer would have preferred that displacement reactions and electric cells be considered as a unit with the other types of oxidation-reduction reactions rather than separating them with three chapters on ionic reactions not involving electron transfers.

The chapter on oxidation-reduction completes the discussion of general principles, which is the main concern of the first half of the book, and the latter half is devoted to the detailed chemistry of the elements. Here again the idea of grouping related topics is competently practiced. Due attention is accorded industrial processes, particularly those which involve instructive applications of principles The flow diagrams for metallurgical processes are to be strongly commended, because they make these discussions the best this reviewer has yet seen. The entire section on the chemistry of the metals has been extensively reorganized and is extremely well done.

A chapter on colloid chemistry is in some respects inadequate. For example, adsorption could well have been given more attention, especially since charcoal was so briefly discussed in the earlier chapter on carbon.

Two chapters on organic chemistry at the end of the book supply as much information as any elementary course can use, and should make possible, at least, an appreciation of the modern accomplishments of this important branch of chemistry. These chapters could of course be omitted if the students intend to pursue further study in chemistry, but they are certainly essential for those whose study ends with the first year course.

The text appears to be unusually free from errors, even though one of the first numbers encountered, Avogadro's number, is given as 6.064×10^{23}, Millikan's old value, while the correct value is now taken as 6.0228×10^{23} ($\pm 0.0011 \times 10^{23}$). The formula of lauryl alcohol on page 582 contains a typographical error, which is the

only other error the reviewer observed. A well chosen type and format result in attractive and readable pages, and the book is a handsome volume.

The reviewer can recommend this text strongly for use in courses which are intended to prepare students for further study in chemistry, or for any class of able students. The thorough and comprehensive discussions which are so valuable for these students might, however, have the effect of overwhelming students with little scientific aptitude, so that judicious pruning of some material would probably have to be practiced with a class of such students.

LLOYD A. WOOD.

Adsorption; by C. L. MANTELL. Pp. viii, 386. New York, 1945 (Chemical Engineering Series, McGraw-Hill Book Co., $4.50) — The viewpoint throughout this book is well expressed by a sentence from the Preface (p. v): "For those who desire it, a brief chapter on theories of adsorption is included, but there is a reminder that the operational man or the designing engineer is more concerned with pressure drops, dry gas capacities, and volumes throughput than he is with theories." The Author gives in this volume a wealth of information, well documented, covering the engineering features of applications of adsorption. But he restricts adsorption by definition (p. 1) to solid adsorbents, and this restriction makes the Reviewer feel that the title of the book is too inclusive.

The material is treated in several ways· according to the adsorbent, or according to the process, for example. Thus in general the manufacture, properties and applications are discussed, and where possible tabulated, for fuller's earth and activated clays (Chapter III); aluminum oxide base materials (IV); bone char and related materials (V); decolorizing carbons, water-treatment carbon (VI); metal- and medicinal-adsorbent chars (VII); gas-adsorbent carbons (VIII); silica gel (IX); magnesia and hydrous oxides (X); and ion exchangers (XVI). These chapters are supplemented with others which deal with operations: the unit operation of adsorption (I); solvent recovery and adsorption from gases (XI); odor removal (XII); gas masks (XIII); dehydration of air and gases (XV); chromatographic adsorption analysis (XVII). There is also the brief chapter on theories of adsorption (II); a chapter (XIV) on gas hydrates which discusses their nature, and the means used to prevent the trouble they may cause in natural gas pipe lines; a chapter (XVIII) which discusses the inspection, specifications and testing of adsorbents; and an appendix in which are gathered very useful tables, and discussions of fundamental laws, energy relations, and conversion factors. A great deal of specific information is given throughout the book on working applications of adsorption, with charts of physical data, flow-sheets,

sometimes diagrams of apparatus and photographs of actual installations, as well as data on operating costs, all of which are clearly of great value to the engineer and "operational man." There are also frequent summaries as for example of the advantages of a given treatment, or the characteristics necessary in a given material for a certain process.

Your Reviewer must state, with some reluctance, that this book in his opinion shows evidence of careless writing. The style is disjointed. Sentences appear occasionally out of context or with little relation to preceding and following sentences. In at least one case an entire paragraph appears out of context, as on p. 336, where a paragraph on the use of fritted bubbler tubes to insure saturation equilibrium between air and carbon tetrachloride appears in the midst of a discussion of the use of *m*-xylene for determining heats of wetting. On pages 343-344 an apparatus is described with letters which would seem to refer to various parts of an illustration, but no illustration is present. Sometimes graphs or other figures are given with no clear indication of whence they were derived (for example, Tables 37, 38, Figs. 38, 87, 134 and others). Some seven misprints came to the notice of the Reviewer. These defects make the book difficult to read, though they do not in themselves detract from the essential contents of the volume. It appears, however, that a useful book has been marred by careless writing and poor editing, and this is not at all in line with the excellence of other books in this series.

Anyone who reads this book will be struck anew with the wide range of applications of adsorption processes in industry and with the versatility of application of which adsorbents are capable: phases of the subject which are well developed by the Author. The book is well made, the type is clear, and the quality of the photographs is excellent. It is indeed unfortunate that the obvious merits of the book have to be shadowed by its faults

HAROLD G. CASSIDY.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Archaeological Investigations in El Salvador; by JOHN M. LONGYEAR III, with an appendix by STANLEY H. BOGGS. (Memoirs of the Peabody Museum of Archaeology and Ethnology, Volume IX, No. 2, 90 pages, 15 plates and 30 text illustrations, Cambridge, 1944).—This monograph is a report on one of the projects of the Institute of Andean Research under the sponsorship of the Co-Ordinator of Inter-American Affairs. In the past the archeology of El Salvador has been sadly neglected, but this report, which is the most extensive to date, is gladly welcomed.

The body of the paper consists of three parts, of which Part I

is introductory in nature, presenting background material and discussing the archeological problems. Part II is "Archaeological Reconnaissance," which gives in outline form the results of surveys carried on by the author and Stanley H. Boggs. With a few exceptions all of the sites listed were visited by the authors. These site descriptions have been written in a concise manner which will enable future field workers to locate the sites easily.

Part III, the major section of the paper, is a detailed description of excavations at Los Llanitos, a site in the southeastern section of the country. The ruins consist of twelve small mounds arranged according to a definite plan and with a similar orientation. Longyear's investigations consisted of the partial excavation of a ball court and three mounds. The greater part of the time was spent on the ball court as it is the most southerly known example of this type of structure. Excavation revealed this court as a long, narrow, dirt floor, bordered by narrow mounds. The other mounds excavated were apparently pediments for structures similar to the modern mud and wattle hut. The mounds were composed of one or more interior walls of pumice blocks set in adobe mortar, and were covered with a soil fill. There was no exterior facing of stone or plaster.

A large collection of potsherds and minor artifacts was secured. This pottery exhibited such a uniformity that the author believes that only a single period of occupation is represented at the site. It was difficult to correlate the material from Los Llanitos because of the lack of excavated sites in the surrounding areas. The architecture and pottery are unique, local developments. Although this site is located in the former Lenca linguistic territory, the archeological material is not similar to that attributed by other workers to the Lenca. No recognizable influence from the east was found, but some trade wares came from the west. On the basis of this trade ware, Longyear hesitantly places the occupation of this site as contemporaneous with some part of the Acropolis Phase at Copan, which dates from about 853 A.D. to 1060 A D

The balance of the monograph contains five appendices of which two are of major importance. Appendix C is "Excavations In Central and Western El Salvador," by Stanley H. Boggs. In this extensive report, which equals that of Part III, accounts of excavations at the site of Tula and Tazumal are presented Tula is a small site of three mounds situated near the west central part of the country. These mounds were in part composed of volcanic ash which covered a small temporary camp. The pottery from this site is of the general types common to El Salvador. On the basis of pottery it is believed that this site is contemporaneous with late Tazumal and the Campana-San Andres group.

. The site of Tazumal, located in the extreme western portion of El Salvador, has thirteen mounds, of which portions of two were excavated. This work revealed two stratigraphically separate groups of pottery. The material of the Early phase was found in a deposit underlying the platform of a large mound while most sherds of the Later phase were found while clearing the steps, terraces and similar surface features. On the basis of trade material the Early phase is probably equivalent in date to the Esperanza Period at Kaminaljuyu, Guatemala. The Later phase includes such trade wares as plumbate ware and Nicoya polychrome, as well as local wares which indicate a relationship with Campana-San Andres and Tula.

Appendix D is a complete "Site List of El Salvador" compiled from the field work of Longyear and Boggs plus all available published material. Appendix E is a short discussion of private collections in El Salvador to accompany the large number of illustrations of representative specimens. An extensive bibliography completes the work.

It is to be regretted that the accompanying site map (page 77) has so many limitations. It would have been easier for the reader if the Pan American Highway had been shown since so many references are made to it, and a number of sites discussed in the text are omitted, one of them being the site of Tula.

The monograph on the whole is a very valuable contribution. In addition to the new material presented, the site lists and bibliography make available much information in a concise form for the future student. The fine illustrations showing several hundred specimens of pottery from the whole country are of much value as comparative material for the archeologists working in surrounding areas.

JOHN M. GOGGIN.

General Meteorology; by HORACE ROBERT BYERS. Pp. x, 645; 300 figs. New York and London, 1944 (The McGraw-Hill Book Co, $5.00).—In reading *General Meteorology*, by Prof. Horace R. Byers of the University of Chicago, one is led to speculate on the mathematical mind. The book is a general text book written with special reference to aviation, but designed to be a full treatment of the science of meteorology. It contains excellent descriptive material which is of interest to the layman. A good deal is said about the use of instruments, which is desirable for the technical observer. The major part, however, is devoted to the physics of the atmosphere. An attempt is made to avoid abstruse mathematics, but taken as a whole the book is fundamentally a mathematical presentation of the laws of physics so far as they apply to meteorology.

In spite of these good features the book is disappointing because it fails to recognize that mathematical treatment is valid only if based on sure foundations. The book treats meteorology as though it were a completely known science, whereas at least one of its most basic factors is still unknown. Occasionally, as in the chapter on hurricanes, there is a hint that there are weather conditions which we cannot explain. In general, however, three of the most important and puzzling meteorological problems are ignored. First, storms frequently show sudden changes in intensity or direction of movement, thereby going counter to predictions. Second, the same or similar phenomena repeat themselves in cycles. Third, the same calendar month may have very different weather from one year to another.

This book makes no attempt to explain these problems. In fact it scarcely mentions them. Nor is there any hint that the laws so well discussed may perhaps need to be supplemented by other laws dealing with the ultraviolet light, the lofty ozone layer, the electromagnetic activity of the sun, or some other unknown factor which changes the course of a hurricane, for example. If meteorological research is to be stimulated a text book assuredly ought at least to inform the student that the laws which it lays down fail to explain certain important and vital conditions.

ELLSWORTH HUNTINGTON.

Seeing The Invisible; by GESSNER G. HAWLEY. Pp xv, 196; 71 figs. New York, 1945 (Alfred A. Knopf, $2.50).—*Seeing The Invisible* is an elementary but somewhat exhaustive story of the electron microscope and its achievements. While it is written primarily for the layman, with considerable emphasis on why we are interested in the microcosm, almost every scientist will be fascinated by this collection of photographs taken with the electron microscope.

Mr. Hawley begins with a discussion of why we are interested in the minute elements of our surroundings, and builds up the interest of the reader by giving a preview of some of the results of the electron microscope. He then takes up the theory of the instrument by first discussing how we see and the dependence of seeing upon the "light," clearly illustrating the difference between magnification and resolving power of an optical instrument. He follows the theory with the history of its development, and later its limitations. Last, and probably the best part of the book, is the discussion of some fifty excellent photographs of interest to the scientist and illustrating why science is interested in these things.

If one must find fault with the book, it would be with the chapters on theory. Here Mr. Hawley drops into the layman's language and emerges with some of the layman's confusions. The expression "Current of strength 60,000 volts," page 57, exemplifies this point.

The reviewer also doubts whether the physicist would agree with Mr. Hawley's definition of "Radiation" However, since these *expressions occur in the more technical chapters,* they are likely to pass unchallenged by most readers.

On the whole, the book presents a stimulating and thought-provoking discussion of the various phases of the subject.

ROLAND MEYEROTT.

PUBLICATIONS RECENTLY RECEIVED.

Virginia Geological Survey Bulletin 60 Geology and Mineral Resources of the Burkes Garden Quadrangle, Virginia; by B N Cooper. University, 1944

Volcanoes as Landscape Forms; by C. A. Cotton Christchurch, New Zealand, 1944 (Whitecombe & Tombs Ltd., 32/6d)

The University of Missouri Studies. Vol. XIX, No 3 The Geology of Missouri, by E. B Branson Columbia, 1944 Price $3 00.

Principles of Physical Geology, by A Holmes New York, 1945 (The Ronald Press, $4 00)

The Chemical Process Industries; by R N Shreve New York, 1945 (McGraw-Hill Book Co, $7.50)

Synthetic Rubber from Alcohol A Survey based on the Russian Literature, by A. Talalay and M Magal New York, 1945 (Interscience Pub. Co, $5.00).

Ebulliometric Measurements, by W. Swietoslawski. New York, 1945 (Reinhold Pub Corp, $4 00)

Textbook of Organic Chemistry; by E Wertheim Second Edition Philadelphia, 1945 (The Blakiston Co, $4 00)

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Mainsprings of Civilization, by E Huntington New York, 1945 (John Wiley and Sons, $4 75).

Infared and Raman Spectra of Polyatomic Molecules, by G. Herzberg. New York, 1945 (D Van Nostrand Co, $9 50)

How To Solve It· A System of Thinking which can help you solve any Problem; by G Polya. Princeton, N J, 1945 (Princeton University Press, $2.50).

Careers in Science; by P Pollack New York, 1945 (E. P. Dutton and Co, $2 75)

The Background of Electrical Science Soul of Amber, by A. M. Still. New York, 1945 (Murray Hill Books, Inc, $2 50).

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The Meaning of Relativity, by A. Einstein Princeton, N. J, 1945 (Princeton University Press, $2 00).

A Revaluation of Our Civilization; by F. R. Wulsin, et al. Engineering and Science Series, No. 57 Albany, N Y, 1944 (The Argus Press).

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THE LATE CARBONIFEROUS VERTEBRATE FAUNA OF KOUNOVA (BOHEMIA) COMPARED WITH THAT OF THE TEXAS REDBEDS.

ALFRED SHERWOOD ROMER.

ABSTRACT. The late Carboniferous vertebrate fauna from Kounova, Czechoslovakia, originally described by Fritsch, is redescribed and compared with the essentially contemporary fauna of the Texas redbeds. The assemblages from the two areas are strikingly similar, suggesting intimate geographical connections between Europe and North America in late Paleozoic times.

A SERIES of vertebrates from a late Carboniferous deposit at Kounova, Czechoslovakia, was described by Fritsch in his "Fauna der Gaskohle" (1879-1904). Little attention has been paid to this material by later writers (except for brief notes on certain of the species by Steen, 1938). Restudy of this fauna which I had undertaken in connection with a survey of Paleozoic amphibians indicates that it is worthy of re-description. Recent advances in our knowledge of early vertebrates makes it possible to interpret these fragmentary remains in a much more satisfactory fashion than could be done in Fritsch's day; the fauna, restudied, seems closely comparable to that of the nearly contemporaneous Texas redbeds assemblage, a situation with suggestive palaeogeographic implications.

The Kounova locality. Kounova lies some 35 miles northwest of Prague in the Rakonitz coal basin. The material studied by Fritsch appears to have come from a single mine, operated for a relatively few years, which supplied coal to the gas-works at Prague and other towns. The fossils were found in blocks of an impure shaly coal of the sort usually (although incorrectly) called a "cannel-coal" in North America. Fritsch (1879, vol. I, pp. 21-22) gives the general section and also the details of the layers normally present in the "cannel."

Kounova lies close to the Carboniferous-Permian boundary (cf. Broili 1908; Case 1926, 53-66; Nemejc 1932; Steen 1938,

266-269). In earlier years it was frequently considered as Permian. The flora, however, appears to be technically a Stephanian one, and hence Kounova must be classed as Carboniferous, although very close to the period boundary.

The Wichita group of Texas,[1] with which comparison is made, likewise lies in disputed Carboniferous-Permian territory. The writer (1935, pp. 1642-1657, etc.) has in the past argued that much of the Wichita should be considered as late Carboniferous rather than Permian. The most important criteria in this connection, however, are those derived from paleobotanical data. Recent work by Read, although not as yet published, is cited by King (1942) to show that *Callipteris,* diagnostic of the Autunian stage of the lower Permian, makes its appearance at the level currently considered as the base of the Wichita.

The Wichita is thus later than the stage represented by Kounova; but although the two are arbitrarily separated by an arbitrary period boundary, the actual time interval need not have been very great. I have repeatedly pointed out that the Wichita fauna was not one newly evolved at the time, but appears to have its roots in the Carboniferous, and similarities between an early Autunian fauna and one from the late Stephanian are thus to be expected. In North America vertebrates of pre-Wichita age, which are probably closer in time to those of Kounova, are known from the Pennsylvania-West Virginia-Ohio region and possibly other areas, but these faunas are as yet too poorly known to make comparison profitable.

Certain differences which exist between the Kounova and Wichita vertebrate assemblages are correlated with the nature of the deposits and the nature of the conditions under which deposition occurred The Kounova remains are preserved on the surface of slabs of the "cannel." The characteristic Wichita matrix, on the other hand, is a clay, with little lamination, from which the fossils are excavated as three dimensional structures. The Kounova locality suggests deposition in the bottom of a quiet pool; much of the Texas material appears to have undergone considerable transportation. Thus at Kounova there was a better chance for the preservation and recovery intact of remains of smaller animals than in the Wichita clays.

[1] The "classic" Wichita faunas are from the Belle Plains and Admiral formations; lower formations were long considered as pertaining to the Cisco group In recent years, however, there has been a general tendency toward lowering of the boundary, so that the underlying Putnam, Moran and (most recently) Pueblo formations are included in the Wichita.

The Kounova environment seems to have been that of a coal-swamp region in which fishes and aquatic amphibians would be abundant and terrestrial animals rare; the Wichita deposits appear to have been formed by streams whose "catch" included a considerable percentage of terrestrial types. In sum, the Kounova fauna would be expected to include a greater representation of small vertebrates, particularly fishes and amphibians than the Wichita beds; in the latter, a greater percentage of large animals, including more terrestrial amphibians and reptiles, would be expected.

Original faunal list. Below are listed the vertebrates from Kounova as described by Fritsch. It appears unnecessary to refigure this material; full references are given to Fritsch's plates which are extremely valuable despite some inaccuracies. Part of the Fritsch material was studied by me during a visit to Prague a number of years ago, but I have in this revision relied in great measure upon these plates. Not included are several forms from other Bohemian localities which may be of comparable age but are not members of the actual Kounova fauna. Brief discussions of some of the amphibians are given by Steen (1938), but I am not aware of the description of any new forms from Kounova since Fritsch's work.

ACANTHODIAN FISHES.

Acanthodes punctatus III pp. 61-62, fig. 256, pl. 107, figs. 7-9.

SHARK-LIKE FISHES.

Orthacanthus kounoviensis II pp. 107-109, fig. 185, pls. 83, fig. 1, 84; 85; 86, figs. 1-4; 87, figs. 1, 2, 5, 7; 90.

Orthacanthus pinguis II p. 109; pl. 87, figs. 3, 4, 6.

Pleuracanthus ovalis III pp. 13-15, figs. 201-205; pl. 91, figs. 7-10, ? 11.

Brachiacanthus semiplanus II p. 113; pl. 83, fig. 10.

Platyacanthus ventricosus II p. 113; pl. 86, fig. 5.

Tubulacanthus sulcatus II p. 113; pl. 88, fig. 14.

Hybodus vestitus II pp. 97-98; pl. 73, fig. 14.

Vertebrae ? II pp. 113-114; pl. 88, fig. 17.

LUNGFISH.

Ctenodus obliquus II pp. 66-84, figs. 144-148, 164; pls. 71; 72, figs. 4-12; 73, figs. 1-13; 74-79; 80, figs. 5-12.

Ctenodus applanatus II p. 85; pl. 72, figs. 1-3.

CROSSOPTERYGIANS.

Megalichthys nitens III p. 75, pl. 88, figs. 15, 16.

PALAEONISCOID FISHES

Trissolepis kounoviensis III pp 76-80, figs. 277, 278; pls. 109-112

Acentrophorus dispersus III pp 81-83, fig. 279; pls. 113, 114.
Progyrolepis speciosus III pp. 118-120, fig. 308; pl. 131.

AMPHIBIANS.

Ophiderpeton pectinatum I p. 122; pl. 20, figs. 1-10.
Ophiderpeton vicinum I pp. 123-124; pl 19, figs 2-3, pl. 24, fig. 2.
Ophiderpeton corvinii I p. 124; pl. 20, figs. 11, 12.
Sparodus crassidens I pp. 86-88; fig. 40; pls. 9, figs. 1. 2. 4. 8, 9; 10, figs. 1-8.
Hylonomus pictus I p. 89; pl. 12, figs. 14, 15.
Porierpeton nitens II p. 42; pl. 70, figs 9-11, 13.
Macromerion schwarzenbergii II pp. 37-40, fig. 140; pls. 65; 66; 67, figs. 3-14, ? 16-24, ? 26; 68, figs. 10-15, 69.
Macromerion simplex II p. 41; pl. 67, figs. 1, 2.
Keraterpeton gigas II p 42; pl. 69, fig. 8.
Branchiosaurus ? robustus I p. 84; pl. 10, figs. 9, 10.
Branchiosaurus ? venosus I p. 83; pl. 9, figs. 5, 6, ? 7; ? 10, fig. 8.
Dawsonia polydens I, pp. 90-92, figs. 42, 43; pls. 11, 12, figs. 1-13.
Limnerpeton dubium I p 157; pl. 33, figs. 4, 5.
Dendrerpeton ? foveolatum II pp. 8-9, fig. 128; pl. 49, figs. 10-13; 51, figs. 2-9.
Macromerion ? abbreviatum II p. 40; pl. 68, fig. 2.
Macromerion ? bicolor II p. 41; pl. 67, fig. 15; 70, figs. 1-8.
Macromerion ? juvenile II p. 41; pl. 68, fig. 1.
Macromerion ? pauperum II p. 41; pl. 68, figs. 6-9.

REPTILE.

Naosaurus mirabilis III p. 121; IV pp. 86-87, fig. 386.

These groups may be reviewed in turn. As will be seen, many revisions of Fritsch's lists are necessary, and many of the tetrapod forms are to be re-interpreted in the light of newer knowledge of other faunas.

Acanthodian fishes. The "spiny sharks," mainly characteristic of the Devonian, survived into the Permian, in Europe at least, but because of their typically delicate structure and small size are preserved in the late Paleozoic only under particularly favorable circumstances (such as those at Lebach). From Kounova only a few spines of *Acanthodes* are reported, in Texas none has been positively identified.

Shark-like fishes. The Pleuracanthodii were apparently common inhabitants of fresh waters in the late Carboniferous and early Permian. Their remains are common at Kounova;

much of the material illustrated in Fritsch's plates 83-87 and 91 are Kounova specimens belonging to this group. Some of the material consists of the calcified cartilages of jaws, visceral arches and braincase; spines, usually with the characteristic double row of denticles, are not uncommon; teeth, showing variants of the characteristic three-pronged pleuracanth pattern are abundant. Fritsch attempted to distinguish three genera—*Pleuracanthus*, *Orthacanthus*, *Xenacanthus*—among his specimens of Carboniferous and Permian pleuracanths from Bohemia. Most of the material from Kounova is placed by him in a single species, *O. kounoviensis*, a large form with spines of the *Orthacanthus* type. A second supposed species of *Orthacanthus*, *O. pinguis*, is distinguished by the fact that the two rows of "teeth" on the spines are more widely separated than in *O. kounoviensis*. However, this character seems to be a variable one (note, for example, the variations between specimens included by Fritsch in *O. bohemicus* of Nyran, pl. 83, etc.) and does not seem to be valid. On the other hand, *Pleuracanthus ovalis*, in which the "teeth" are set on the lateral margins of the spine, appears to be a valid although relatively rare form.

Fritsch gave several other names to fragmentary specimens which are apparently pleuracanthid in nature; it is probable—although impossible to determine definitely — that they are synonymous with *O. kounoviensis* as the common pleuracanth in the deposit. *Brachiacanthus semiplanus* from Kounova is represented by a single unornamented spine of a sort which Fritsch elsewhere ascribes without hesitation to *Orthacanthus* (cf. pl. 83, fig. 10, with pl. 82, fig. 18, etc.). *Platyacanthus ventricosus* of Kounova (pl. 86, fig. 5) is a spine very closely comparable to the type of "*Anodontacanthus*" *americanus* of Hussakof (1911, pl. 26, fig. 5). As I have recently pointed out (1942, p. 227) this latter form is probably a pleuracanth. *Tubulacanthus sulcatus* is known only from a spine tip, apparently much weathered, seemingly indeterminate, but possibly pleuracanth in nature. *Porierpeton nitens* is a name given by Fritsch to certain "porous" skeletal elements which he included among the Amphibia. However, certain of the Texas pleuracanth specimens have a similar texture, and the visceral arch material from Texas includes an element (which I have not identified) comparable to that figured by him as *Porierpeton* in his plate 70, figure 10.

The Kounova pleuracanth material is very similar to that of the Texas redbeds, more especially that in the Wichita formations. Calcified cartilages are not uncommon and may be locally abundant; teeth are very common in many localities. The spines are less common. The few available to me are all of the *Orthacanthus* type; I have not seen the *Pleuracanthus* type of denticulation. The only remains in the Kounova materials indicative of the presence of sharks typical of saline waters is a single tooth described as "*Hybodus*" *vestitus*. In the Wichita such materials are quite rare, but are occasionally found in localities which lie close to marine sediments laterally or vertically and thus may be suspected of having been laid down in brackish waters.[2] Included are several specimens of spines of the *Hybodus* type.

Actinopterygian fishes. The Carboniferous and early Permian were times in which there flourished a great variety and abundance of palaeoniscoids, mainly of small size. In certain deposits their remains are abundant, in other localities (as at Kounova and in the Texas redbeds generally) they are relatively rare. Their rarity as fossils may be attributed in great measure to the fact that they were presumably a staple food supply for many of the contemporary predators as well as to the fact that unusual circumstances must be present for their adequate preservation. At Kounova only three palaeoniscoids were described by Fritsch—*Sphaerolepis* (*Trissolepis*) *kounoviensis*, "*Acentrophorus*" *dispersus*, *Progyrolepis speciosus*. Obviously this is not a fauna adequately representing the assemblage of palaeoniscoids present in Europe at the time, but merely an inadequate "random sample." Of the three forms, *Sphaerolepis* is represented by a fairly good set of materials and appears to be a good generic type without close relationships. The other two are inadequately known; I am not aware of any recent discussion of their nature or relationships by students of the palaeoniscoids except for Gill's note (1923, p. 38) that "*Acentrophorus*" *dispersus* does not belong to that genus.

In the Wichita (cf. Dunkle, 1939) we find likewise a sparse and not too representative assortment of palaeoniscoids, most of them also inadequately known; only five species are reported from both the Wichita and the overlying Clear Fork beds com-

[2] I have recently reviewed such finds (1942, 220-227); in addition to the forms then known there has since been discovered in the Wichita a tooth of cochliodont type (cf *Deltodus*).

bined. Two of the three Kounova genera may be present. *Sphaerolepis* is reported but doubtful. *Progyrolepis* is not recorded in the American literature, but Dr. D. H Dunkle informs me that he is currently studying Wichita material of this genus.

Lungfish. A large percentage of the Kounova material consists of tooth plates and other bones of lungfishes. Most were first described by Fritsch as *Ceratodus barrandei* but later ascribed by him to *Ctenodus obliquus* (the type material of which is from the Westphalian of Newsham). This material has been discussed by Watson and Gill, (1923) who identified many of the elements figured by Fritsch. As these authors note, the Kounova lungfish belongs to the genus *Sagenodus*. It is none too likely that the species is the same as that found in England at a much earlier time, and the Kounova lungfish may be appropriately termed *Sagenodus barrandei*. Two specimens of dental plates from Kounova were smaller and differed in various points from the majority of the finds and hence were regarded by Fritsch as a separate species, *Ctenodus applanatus*. Similar plates in American materials have been found to be nearly immature specimens of "normal" *Sagenodus* plates and, *applanatus* can be confidently regarded as a synonym of *barrandei*. Certain bones included by Fritsch among the supposed amphibian material seem also to pertain to *Sagenodus*. Thus his plate 67, figure 14 is a *Sagenodus* quadrate (cf. Watson and Gill, fig. 11), and figure 20 of the same plate is perhaps a second specimen of this nature; plate 70, figures 6 and 7 may be a lungfish jaw element, as Fritsch himself suggested

In Europe the genus *Sagenodus* is unknown beyond the time at which the Kounova sediments were deposited; indeed, as far as I am aware, no later Paleozoic (Permian) dipnoans are known from that continent except for the rare and very aberrant *Conchopoma* from Lebach and two specimens from beds regarded as basal Permian and hence only slightly later than Kounova. These last include a single specimen from Koschtialov, Bohemia, named "*Ctenodus*" *tardus* (Fritsch, pl. 80b) and another from Igornay in the Autun basin — *Megapleuron rochei* (Gaudry 1883, fig. 246). Both are nearly complete fishes, but cranial and dental features are obscure and generic assignment is impossible. This paucity of Permian lungfishes is in strong contrast to their abundance in earlier deposits and again in the Triassic.

A somewhat different situation is found in the North American Permian. There are few traces of lungfishes in the Clear Fork beds, but in the middle and lower parts of the Wichita *Sagenodus* is present and abundant despite the definite palaeobotanical evidence of the Permian age of these beds. Earlier Wichita finds (some then considered as Cisco) were reviewed by Romer and Smith (1934, 711-714); during the past decade a wealth of *Sagenodus* plates and teeth have been found as the result of work by the Museum of Comparative Zoölogy in the lower levels of the Wichita. This material is strikingly similar to that from Kounova pictured by Fritsch, both as to its general nature and the range of variation present; if we did not know otherwise, the Kounova material could be readily accepted as derived from a Texas locality.

Crossopterygians. Of the two major types of late Paleozoic crossopterygians, coelacanths are as yet unidentified from Kounova and, while definitely present in the Texas beds, are rare and were not identified there until recent years (Westoll, 1937). Of the typical crossopterygians (Rhipidistia) the last known representative in Europe is *Megalichthys* of the Carboniferous, none are known there in the Permian. Fritsch reports and figures scales of this genus from Kounova. In America the rhipidistians (like *Sagenodus*) persisted later than in Europe, for there have been found at several localities in the middle and lower portions of the Wichita specimens of *Ectosteorhachis*, a genus close to *Megalichthys* and often considered synonymous.

Amphibians. Fritsch lists from Kounova eighteen species of amphibians, assigned to ten genera. The deposit is especially rich in amphibian material, but this list needs considerable revision.

Most of the amphibian material pertains to members of the important labyrinthodont group. Apart from several rhachitomes there is positive evidence of the presence of an embolomere highly comparable, in such respects as are known, to the Wichita form usually termed *Cricotus* but apparently more properly called *Archeria*.[3] The most distinctive material consists of two typical embolomere pelves (pl. 66, figs. 1, 2; pl. 67,

[3] The genus *Cricotus* was based upon embolomere vertebrae from the lower Stephanian of Illinois. It is very improbable that the embolomerous form or forms from the Texas deposits of considerably later age are generically identical. However the humerus described by Case (1915, 170) under the name of *Archeria* is that of the Texas "*Cricotus*" and it appears unnecessary to coin a new term.

figs. 1, 2). Fritsch correctly identified them as pelves, but misinterpreted their structure. They are very similar to the pelvis of *Archeria*. The first is somewhat larger than any complete Wichita specimen of that genus, but there are fragmentary remains of Texas embolomeres of this size; the second specimen is somewhat small and apparently somewhat immature. Apart from the pelves, other definitely embolomere remains are few. Plate 66, figure 5 is a typical embolomere intercentrum; figure 4 of the same plate is a femur with incomplete ends (? immature, or weathered?) which as far as preserved compares well with that of "*Cricotus*." I cannot be sure of the nature of plate 66, figure 3. The spine-like structure of plate 69, figure 8, called *Keraterpeton giganteum* by Fritsch appears to be, as he suggested, a tabular ("epioticum"), but of an embolemere, not a nectridian. Apart from this, however, I am unable to identify with confidence any embolomere material among the remains of skulls and jaws from this locality; most of them appear to belong to rhachitomes. *Archeria* is distinguished generically by the possession of closely-crowded slender teeth with somewhat chisel-like tips; no such teeth are known from Kounova, and none of the jaw fragments preserved is sufficiently complete to show whether other characteristic embolomere features were present.

The Kounova embolomere material was included by Fritsch in his genus *Macromerion*. This, however, included a melange of various amphibian and reptilian remains, as recognized by Steen (1938, p. 262), and it seems best to utilize the name for the reptile. In default of any proof of identity with *Archeria* it seems inadvisable to refer it to the American genus. *Memonomenos* (Steen, 1938, p. 240) is a Bohemian genus of approximately the same age which is probably an embolomere, and the Kounova form may be provisionally referred to it as *Memonomenos simplex* (the specific name has as a holotype a characteristic pelvis).

Rhachitomous amphibians were at one time believed to be almost entirely confined to the Permian; we now know, however, that they were abundant well back in the Pennsylvanian, and they appear to have formed a large percentage of the amphibians present at Kounova as in the Texas Wichita. There are apparently nine names (the last nine of the list given above) applicable to Kounova rhachitomes. The material, however, is so fragmentary that it is difficult to get any adequate idea

of the nature of the forms concerned or to compare them with Texas genera The situation is complicated by the fact that the type of fossilization at Kounova favors the preservation of larval or immature specimens as much or more than adults, so that size is not useful as a criterion for distinguishing one form from another. There are certainly two or three rhachitomes present; possibly a few more; but it is probable that many of the available names are synonyms.

Evidence of the presence of a rhachitome of rather good size comparable in nature to *Eryops* of the Texas deposits and to *Onchiodon* and *Actinodon* of Europe is afforded particularly by the partial jaws shown by Fritsch in plate 68, figures 2 to 9, to which the names *Macromerion ? abbreviatum* and *M. ? pauperum* were given. As may be seen (cf. Sawin, 1941; pl. 5) these jaws appear highly comparable to materials of *Eryops* of the Wichita and presumably to the closely related European Lower Permian genus *Onchiodon*. The jaw fragments indicate a form with a skull length of perhaps 22 cm, that is, about half the size of the familiar Middle Wichita specimens of *Eryops*. To this same form belong some or all of the teeth and jaw fragments of plates 67 and 70 referred to *M. schwarzenbergii* and *M. bicolor*; to it may also belong the *Eryops*-like scales of plate 65, figures 4 and 5; plate 67, figure 13; plate 69, figure 7; and such foot material as plate 67, figures 19, 21 and 22. There are, however, no other remains of any large amphibian which can be referred here, and the only other possible material is such "larval" specimens as appear to be of the general *Eryops-Onchiodon* type. One small form of this sort is "*Dendrerpeton*" *foveolatum*, founded on several specimens from Kounova, among which we here specifically designate that figured on plate 51, figure 2 (no. 108) as the holotype. This specimen includes part of the skull and postcranial elements of a small and obviously immature rhachitome, with a supratemporal but no intertemporal bone present in the skull table; particular attention is called to a clavicle (directly back of the left orbit) of the narrow, distally striate type characteristic of *Eryops* and its close kin. Whether or not several other specimens assigned to this species by Fritsch are generically or specifically identical is not certain. The interclavicle figured by Fritsch in plate 10, figure 9 as "*Branchiosaurus*?" *robustus*[4]

[4] As I have pointed out elsewhere (Romer, 1939) *Branchiosaurus* is a term used for small, larval specimens of various rhachitomes.

is a small specimen of the type seen in the *Eryops* group; with this was associated a partial jaw of appropriate size. "*Branchiosaurus*" *venosus* is the name given by Fritsch to a number of parasphenoids[5] from Kounova (pl. 9, figs. 5-7; cf. also pl. 10, fig. 8). One or more of these may well belong to the type of rhachitome here discussed, and we may note a similar parasphenoid forming part of the type of "*Dendrerpeton*" *foveolatum*.

There is a considerable amount of Kounova material representing both upper and lower jaws of small amphibians. We may note specimens seen on plate 49, figures 10-13; plate 51, figure 3 ("*Dendrerpeton*" *foveolatum*); plate 67, figure 15 (*Macromerion bicolor*); the angular of plate 67, figure 12. Some of this material may belong to the present form, but certainty is impossible. It must be remembered that little diagnostic value can be placed on the distribution of teeth in a labyrinthodont jaw ramus because the type of tooth replacement (in alternating waves) would give the same jaw seemingly very different types of dental equipment at different periods.

There is thus considerable probability—although in individual points little certainty—that much of the Kounova amphibian material pertains to varied growth stages of a rhachitome similar to *Eryops* of the Wichita.

The first specific name applied to any of the material discussed is *foveolatum*. Generic assignment is difficult; no generic name used at Kounova is available. Geographical "propriety" suggests the use of a European name; *Onchiodon* is a seemingly closely related form of somewhat later date We may therefore term this rather synthetic amphibian *Onchiodon*? *foveolatum*.

Dawsonia polydens was founded by Fritsch on the basis of a number of fragmentary specimens of small amphibians illustrated in plates 11 and 12. The most important single specimen is his No. 106, which may be specifically designated as the holotype It is by no means sure that all these materials belong to the same animal. The holotype includes a rhachitomous neural arch (pl. 12, fig. 5); a feebly ossified scapula; some inadequate remains of limb and girdle elements; sculptured elements (pl. 12, fig. 6) which may be an expanded clavicle and interclavicle, some well sculptured skull bones; a parietal

[5] Bulman and Whittard (1926, 558) consider them as interclavicles, but they are surely incorrect in this statement

viewed from the ventral surface; an interclavicle. Fritsch associated with the type several other specimens in which the most characteristic element is the pterygoid. This is a puzzling element (it will be noted that although several pterygoids are figured by Fritsch on plate 11, none is present on the holotype). There appears to be a very deep quadrate (and otic) ramus, but the nature of the braincase articulation is not clear, and there is no evidence of the normal labyrinthodont pterygoid flange. The palatal ramus as preserved is a long, slender structure, heavily denticulate. I know of no well-known labyrinthodont comparable in respect to the pterygoid. Two of the pterygoids figured by Fritsch show along the lateral margin a row of teeth at right angles to the pterygoid's palatal surface. Possibly these may be a row of teeth on palatine and ectopterygoid.

There is no conclusive evidence that this palatal material belongs to the same amphibian as the holotype. The association rests on the fact that the parasphenoid associated with one of the palatal specimens appears to be similar to the holotype parasphenoid. The "microsaurs" *Pantylus* and *Sparodus* (the latter apparently present at Kounova) have a comparable pterygoid structure, and it is not impossible that the palatal material belongs to the latter genus.

No confidence can be placed on Fritsch's restoration of the skull roof from isolated elements, some of them of questionable nature. In this connection we may note the skull table named *Macromerion ? juvenile* (pl. 68, fig. 1). This is of appropriate size for *Dawsonia.* The upper surface, where seen, is strongly sculptured. The skull table is relatively long and narrow, as compared with eryopids. There are typical otic notches; cheek elements appear to have been firmly united to the table as in rhachitomes and in contrast with typical embolomeres. The sutures surrounding the postparietals ("oberes Hinterhauptbein") indicate that the tabulars were small in diagnostic rhachitomous fashion. Sutures are not readily seen in the temporal region in Fritsch's figure, but Steen (1938, 262) states that (in contrast with the *Eryops* group and most Permian genera) both intertemporal and supratemporal were present; it will be noted that the parietal of the *Dawsonia* holotype (pl. 12, fig. 3) is incised along its lateral margin as if for the reception of this element. It is, hence, possible that this skull table is that of *Dawsonia*, and that the form is a primitive

rhachitome of the *Trimerorhachis* type known in the Texas Wichita.

Of the second major division of Paleozoic amphibians—forms with "holospondylous" vertebral centra, i.e., the lepospondyls in a broad use of that term—two types are clearly present at Kounova. *Ophiderpeton*, a snake-like aistopod common in earlier Pennsylvanian deposits, is represented, apparently by a single specimen. This is described as *O. vicinum*. Two other specific names are given to specimens of the "kammplatten" which Fritsch believed to belong to *Ophiderpeton*; I have nothing to add to the controversy regarding the nature of these structures. *Ophiderpeton* is not reported from the Wichita; a small and delicate form of this sort is not likely to be preserved there.

A second, and very different, lepospondyl is *Sparodus crassidens*. As I hope to point out at another time, *Sparodus* is closely related to *Pantylus*, known only from the Clyde Formation of the Wichita group. *Pantylus* is not, as usually stated, a cotylosaurian reptile but a lepospondylous amphibian of the "microsaur" group. "*Hylonomus*" *pictus* is the name given to an amphibian jaw fragment with blunt teeth; it is indeterminate, but may well belong to *Sparodus*.

Reptiles. In his earlier descriptions no reptiles of any sort were recognized by Fritsch at Kounova. Later he recognized a single specimen as reptilian. It now seems clear that at least two are actually present in the material.

A small spine fragment from Kounova was at first thought by Fritsch to pertain to a fish. Later, with the publication of descriptions of American specimens of the *Edaphosaurus-Naosaurus* type, he realized its identity (cf. Romer and Price 1940, pp. 388-389) with them. *Edaphosaurus* is one of the common pelycosaurs of the Wichita, but the American species of this age are larger; the smallest Wichita specimen known to me has a length of centrum twice that of Fritsch's. The somewhat earlier age of Kounova may account for at least part of the size difference; there appears to have been a steady increase in the size within the *Edaphosaurus* "phylum" during Wichita time.

The name *Macromerion schwarzenbergii* seems properly applicable to a large pelycosaur which can be definitely identified as such in the Kounova cannel although only a small percentage of the material described under this name belongs here.

I am embarrassed to find that this material was overlooked by Price and the writer in our recent review of pelycosaurs (1940) due to its "burial" in Fritsch's work amongst a series of amphibian remains. The most characteristic piece is the upper jaw fragment figured by Fritsch on plate 65, figures 6 to 9. This is an inner view of a right maxilla which in almost every respect is very closely comparable to that of *Dimetrodon* and other typical American sphenacodonts (cf. Romer and Price 1940, pl. 9). The anterior portion is missing, and with it the large pair of "canines" characteristic of sphenacodonts; Fritsch, however, notes that the base of a large canine is present. There are eight post-canine teeth preserved, whereas 12 or 13 are common counts for Wichita sphenacodonts; the bone is, however, incomplete posteriorly and several additional small teeth may have been present in life. There is a thick supracanine swelling of the type characteristic of sphenacodonts and even an indication of the antero-posterior groove seen to cross this swelling in well preserved sphenacodonts. The dorsal margin of the bone is, as in American sphenacodonts, thin and irregular along its line of suture with the lacrimal. At the lower left hand margin of the specimen is seen the deep recess into which fitted the anterior end of the palatine, a bone which here formed the posterior margin of the choana. The teeth are, as in American sphenacodonts, somewhat recurved and compressed at their tips. The size of the maxilla is appropriate for a sphenacodont little smaller than *Dimetrodon limbatus*, the typical Wichita form.

A second specimen which may well belong to the same animal is an interorbital region of a skull roof, seen in plate 65, figure 1. This bears a somewhat rugose surface as in large sphenacodonts. It seems probable that the whole central portion of the specimen consists of a pair of elongate sphenacodont frontals and that the apparent diagonal lines crossing these two elements are cracks rather than sutures. On the left side is a clear suture outlining the prefrontal. Posterior to this, it would seem that the postfrontal excludes the frontal from the orbit, an unusual (although not impossible) condition for a pelycosaur; however, the apparent inner border of the postfrontal may be a crack rather than a suture.

The bone in figure 2 of the same plate, which Fritsch thought might be a fish vomer, is a reptilian pterygoid, probably although not certainly pelycosaurian. The teeth crowning the

flange are only preserved in part and are rather small, relatively, for a sphenacodont; and as an isolated structure the pterygoid could be interpreted equally well as an ophiacodont. In size it is a bit small for the other skull material just described, but it might nevertheless pertain to the same animal. The vertebra of plate 65, figure 3 is an appropriate pelycosaur caudal. The limb bone of plate 69, figures 2 and 3 is the proximal part of a left tibia, identifiable in every particular as that of a sphenacodont. Except that it is slightly immature and that, hence, the articular surfaces are less completely ossified, it can be directly compared with a tibia figured by Romer and Price (1940, pl. 32); it is somewhat small for an animal such as that to which the maxilla belonged. Plate 69, figure 6 is a crushed radius of similar size to the last (cf. Romer and Price, pl. 33). Not improbably the ribs seen in plate 68, figure 10 and plate 69, figures 4 and 5 are of sphenacodont type with the tuberculum broken off—a frequent occurrence in American material.

Of interest is the left pelvic girdle seen from the inner surface in plate 69, figure 1. One's first impression is that it is another embolomere pelvis; but, as far as preserved, it agrees perfectly with those of sphenacodonts (cf. Romer and Price 1940, pl. 28). This similarity is particularly true of the imperfect pubis, seen at the right in lateral view. The ilium as preserved differs from such a species as *Dimetrodon incisivus* in the length and rod-like character of its posterior extension and in the seemingly slight development of the blade. However, a comparable posterior development is seen in other American dimetrodons (as, for example, *D. loomisi*, Romer and Price 1940, fig. 27); the blade is rather variable in its development in American forms.

Certain of the unidentified bones on Fritsch's plate 67 may also belong to this pelycosaur as, for example, figure 18, which appears to be a metatarsal of sphenacodont type. We thus have, in the material here retained or included in *Macromerion schwarzenbergii*, evidence of the presence at Kounova of a good-sized pelycosaur closely comparable to *Dimetrodon* and related sphenacodonts of the Wichita and other American deposits. Since, however, the nature of the spines and other diagnostic features are not known, generic identification with American forms is not at present possible or advisable.

Taxonomic notes. The taxonomy of a series of fragmentary

materials such as this is a difficult matter, and the situation is rendered worse in this instance because Fritsch in general failed to designate genotypes or species holotypes. Some points in this regard are here noted as related to the reptiles and amphibians.

Much of the tetrapod material from Kounova was included by Fritsch in the genus *Macromerion*, with a number of species.[6] No genotype was fixed by Fritsch, but Lydekker (1890, 160), properly, I think, fixed *M. schwarzenbergii* as the type. The material of the species, however, included elements of a lungfish, an embolomerous amphibian, at least one rhachitome, a reptile, and possibly other animals. The holotype is hereby designated as the specimen shown in Fritsch's plate 65, figure 6—a maxilla of a sphenacodont reptile. *M. simplex* is available as a specific (but not generic) term for the Kounova embolomere. *Macromerion bicolor, M.? juvenile, M.? abbreviatum, M.? pauperum* are, as noted above, terms available for rhachitomes from this locality. They date, however, only from 1885 (or 1886?) when pages 33-64 of Volume II of Fritsch's monograph were published; earlier available Kounova names which possibly or probably apply to rhachitomes are those which appeared in earlier portions of that work. These are, in order: *Branchiosaurus? venosus, B.? robustus, Dawsonia polydens, Dendrerpeton? foveolatum, Limmerpeton dubium.* These have been discussed above. Except for *Dawsonia polydens* none of these species is a genotype or should be considered as such.

Sytematic summary. As a result of our review of the Kounova material, the original list of forms given by Fritsch must be considerably modified. There appear to be about 16 forms whose presence at Kounova seems certain. The other species named by Fritsch are in all probability synonyms of those listed below and are given in brackets in the tabulation:

ACANTHODII.

1. *Acanthodes punctatus.*

SHARKS.

2. *Orthacanthus kounoviensis* [*O. pinguis, Brachiacanthus semiplanus, Platyacanthus ventricosus, Tubulacanthus sulcatus*].

[6] *M. bayeri* was described from Nyran; part, at least of the material (Fritsch, pl 64) is that of a good-sized rhachitome. It has an *Eryops*-like shoulder girdle, which Fritsch, followed by Lydekker (1890, 161), mistook for a pelvis (see Steen 1931, 7; Broili 1908, 52-53).

3. *Pleuracanthus ovalis.*
4. *"Hybodus" vestitus.*

ACTINOPTERYGII.

5. *Trissolepis kounoviensis.*
6. *"Acentrophorus" dispersus.*
7. *Progyrolepis speciosus.*

CROSSOPTERYGII.

8. *Megalichthys nitens.*

DIPNOI.

9. *Sagenodus barrandei* [*Ctenodus applanatus*].

LABYRINTHODONT AMPHIBIA.

10. *Memonomenos ? simplex* [*Keraterpeton gigas*]
11. *Onchiodon ? foveolatum* [*Macromerion abbreviatum, M. bicolor, M. ? pauperum, Branchiosaurus, ? robustus B. ? venosus, Limnerpeton dubium, Porierpeton nitens*].
12. *Dawsonia polydens* [*Macromerion ? juvenile*].

LEPOSPONDYLOUS AMPHIBIA.

13. *Ophiderpeton vicinum.*
14. *Sparodus crassidens* [*Hylonomus pictus*].

PELYCOSAURIA.

15 *Macromerion schwarzenbergii.*
16. *Edaphosaurus mirabilis.*

This fauna is, in its general aspects, one representative of the type expected in any European or North American assemblage of the late Carboniferous or early Permian, although the relatively restricted and fragmentary material from this single coal-swamp pool deposit presumably includes but a small part of the total fauna then present in the region. Among the fishes, pleuracanth sharks, the lungfish *Sagenodus* and palaeoniscoids are plentiful. Of the amphibians, there are both embolomeres and rhachitomes, labyrinthodonts and lepospondyls—the latter group nearing the close of their Paleozoic developmental period and not too abundant. Reptilian remains are not expected in any numbers in a coal-swamp deposit of this type, but the presence of *Edaphosaurus* and a typical sphenacodont indicate that the drier land areas may have had a varied fauna of primitive reptiles.

The Kounova fossil material is strikingly similar to that from the Texas Wichita. Many points of similarity have been noted in our discussion of the various groups and forms con-

cerned. The material as a whole is of such a nature that if one familiar with Texas collections were presented with it without knowledge of its origins, he would consider it, with little or no question, as of Wichita origin. Most of the material could be assigned without difficulty to Texas genera (and even species); the relatively few exceptions would not be disturbing since it is common, even today, for any fairly extensive collection from a new Wichita locality to make some new addition to the fauna.

This similarity, however, does not appear in the faunal list as given above. None of the species as listed is a Texas species: relatively few of the generic names used are those of Texas forms. The reasons for this have been implied or stated more than once in our discussion of the various forms concerned. Texas and Bohemia are today regions remote from one another—about 5,700 miles by direct great circle distance across the North Atlantic, 10,000 miles along the shortest land route *via* Northern Asia.

In default of good proof to the contrary, one hesitates to claim generic or specific identity for two animals living in areas so remote geographically from one another.

Despite this conscientious attempt on my part to conceal the similarity of the faunas, their close relationship is still apparent. Of the sixteen genera listed from Kounova, four are definitely Texas Wichita forms and eight others might be generically identical as far as the evidence goes; four are unreported from Texas, but two, at least are based on rare and fragile materials readily overlooked there. Of the sixteen genera, thirteen are reasonably assignable to families known from the Texas deposits, and it is not improbable that further work in the Wichita may lead to future recognition of a complete identity of the faunas on the family level.

Palaeogeographical implications. This remarkable faunal similarity naturally leads to a reconsideration of the palaeogeographic situation. Vertebrate paleontologists have in recent years tended to be, on the whole, conservative in their views on earlier continental connections and relationships. As Matthew (1915) pointed out, nearly all Cenozoic faunal problems are best interpreted on the basis of fixed continents with none but the obvious "natural" connections above continental shelf boundaries between them; Simpson (1943) has recently reviewed the situation and affirmed Matthew's conclusions.

Concerning older geologic periods, however, the geographic picture is less clear as regards the vertebrate evidence. For the Mesozoic in general, continental vertebrate faunas are too few in number and too scattered to give any strong verdict on inter-continental relationships.[7] As regards the late Paleozoic the evidence is not decisive. It is unfortunate that until Permian times our knowledge of fossil vertebrates is almost entirely confined to Europe and North America. There is, however, a considerable body of data which suggests that at that time geographic relationships between these two continents were of a more intimate nature than was the case in the Cenozoic. The Kounova fauna is a case in point.

To explain the Kounova-Wichita similarities on the basis of "normal" continental relationships, one might point out, of course, that Eurasia and North America are today so similar in their faunas that they are often regarded as constituting a single Holarctic region, and argue that the similarities cited here between Texas and Bohemian forms are due to a continental configuration in the late Paleozoic similar to that of the Cenozoic, with intermigration between Europe and North America *via* Asia.

Upon closer examination, this argument loses much of its force. We do have, today, many resemblances between Eurasian and North American faunas. But how great are the resemblances between the two extremes, between North America and Europe—not Asia? Further, many of the faunal resemblances have to do with higher vertebrate groups, the mammals and birds, which can migrate with relative ease and rapidity. How great are, actually, the European — North American resemblances as regards lower vertebrates?

To answer this question I have tabulated and compared the amphibian and reptilian faunas of the two regions.[8] As perhaps the fairest method of formulation, I have put the question in this fashion: Of the genera and families present in Europe, what percentage are present in North America? This treatment is comparable to that given our discussion of the fossil faunas

[7] Von Huene and Nopcsa, notably, have argued ably for various "unorthodox" Mesozoic land connections. It is inappropriate to discuss the data on the present occasion, but I do not feel that their evidence is conclusive

[8] My colleague, Curator Arthur Loveridge, has aided me in this compilation I have not attempted to extend this comparison to the freshwater fishes, since I do not feel competent to deal with the systematic problems involved

The modern European fauna comprises some 51 genera of reptiles and amphibians. Of these, only 12, or about 24 per cent, are also present in North America. There are 21 families present in Europe. Of these only 10, or about 48 per cent, are common to both continents[9] It is obvious that the Kounova-Wichita resemblances were much greater. Generic identities are at a minimum 25 per cent, and may be as high as 75 per cent; family identities are not improbably as great as 87 per cent, and may prove to be still higher. At the end of the Carboniferous, resemblances between the lower vertebrate faunas of Europe and North America were, thus, roughly twice as marked as they are today, if the Kounova assemblage is representative.

If we cling to the concept that late Paleozoic continental relations were similar to those of later periods, how are we to account for the much greater resemblances between Europe and North America at that time? Several possible arguments come to mind. It might be claimed (1) that in the late Paleozoic the migration route *via* Asia was more readily traversed than in the Cenozoic; (2) that a longer period of time had been available for faunal diffusion; and, related to the last assumption, (3) that the Paleozoic groups concerned were old established and stable ones as compared with those involved in the Cenozoic faunal picture.

None of these suppositions appears to carry conviction.

1. We have almost no knowledge regarding the nature of possible land connections *via* Asia in the late Paleozoic, but the Cenozoic connection appears to be about as satisfactory a one as might be desired The history of mammalian faunas indicates that, although, occasionally interrupted, it was freely open for migration for considerable lengths of time at various stages of the Cenozoic. For a relatively short period in very late Tertiary and Pleistocene days, the establishment of sharp climatic gradients would have hampered interchange of American and Eurasian amphibians and reptiles, but during the

[9] The reverse formulation, i e, compiling the larger North American list and determining the percentages of genera and families also found in Europe, gives, as expected, a distinctly lower percentage of common forms. If, however, African occurrences be added to European, the figures are about the same as those given above. It might be argued that the low percentage of common genera might be due to the work of taxonomic "splitters" of genera. However, in most of the types concerned, the genera are apparently broadly drawn

greater part of the Tertiary, climatic conditions, as indicated both by the type of mammal migrants and by the flora (Chaney 1940), were favorable.

2. There is ample evidence that free communications between Eurasian and North American regions were in existence at least as far back as the beginning of the Tertiary, a span of time currently estimated, on the basis of radioactive phenomena, at about 70,000,000 years, and may have existed still earlier. We could not desire any longer span for a similar connection to account for the Kounova situation, for the simple reason that most of the groups concerned would not have been in existence at such an early date. Using a current estimate of 60,000,000 years for the Carboniferous, 70 millions would carry us back well into the late Devonian. Of about 11 orders and 15 families represented at Kounova, only 4 orders are known to have been in existence at such an early time, and not more than two or three of the families had been as yet developed.

3. It might be assumed that the relative lack of similarity between the modern faunas discussed is due to the fact that the types concerned have been in a rapid evolutionary phase, with consequent lack of thorough diffusion. This is not the case. Apart from the snakes, the major amphibian and reptilian groups now present were in existence by the beginning of the Cretaceous, and numerous and varied families representative of all of them were established by late Cretaceous or Eocene times. The snakes are poorly represented in the fossil record and appear to have undergone much of their differentiation during the Tertiary, and in their case alone late Tertiary climatic changes may have been a bar to free intermigration. In the Kounova-Wichita comparison, nine groups of ordinal rank include the common forms. One, that of the hybodont sharks, appears to have inhabited salt waters (although probably littoral) and hence affords unsatisfactory evidence. Two—rhipidistian crossopterygians and lung-fishes — were groups which were established well back in the Devonian and which appear to have evolved but slowly during the Carboniferous; their distribution at the end of that period may be adequately explained on the basis of "normal" continental construction. Three other groups — pleuracanth sharks, lepospondylous amphibians and embolomeres—appear to constitute an intermediate category as regards rate of evolutionary development. There is no reason to believe that any one of them was in

existence before the beginning of the Carboniferous.[10] We know little of them in the lower part of the Carboniferous and hence can say little about the rate of their evolutionary development. It is, however, quite possible that, once established, their development during this period was slow and that, hence, the similarities here between America and Europe could be attributed to communications *via* Asia.

Far different is the case of the three remaining groups—palaeoniscoid fishes, rhachitomous amphibians, pelycosaurian reptiles. Palaeoniscoids appear in the Middle Devonian, but were rare both in numbers and in variety of forms present until the end of the Devonian. Recent work has shown that at about the beginning of the Carboniferous there began within this group an explosive evolutionary phase which continued throughout the remainder of the Paleozoic. The oldest definitely known rhachitomes are mid-Pennsylvanian; there is abundant evidence that they were in a stage of rapid evolutionary advance and deployment during late Pennsylvanian times. The paucity of Carboniferous fossiliferous continental deposits other than those of coal-swamp type is responsible for the fact that we have little idea as to the time at which reptilian evolution began; but the development before the end of the Pennsylvanian of such specialized reptiles as the pelycosaur *Edaphosaurus* and the sphenacodonts is adequate evidence that the early evolution of the reptiles was a very rapid one. Close similarity—in some cases positive generic identity—between representatives in two regions of rapidly evolving groups strongly suggests intimate geographical connections between the areas involved.

The discussion above strongly suggests that in late Carboniferous times the possibilities of intermigration between Europe and North America were much greater than was the case in the Cenozoic *via* the Alaskan-Siberian bridge, and that, therefore, some more intimate type of connection was then present. Were the instance cited the only one leading toward this conclusion, the argument might be dismissed with relative ease. It is not, however, an isolated example. Throughout the later Paleozoic we find that in every case in which faunas of the same age and from the same general environment are known from the two sides of the Atlantic, they are remarkably similar in nature (cf. Nopcsa 1934).

[10] Citations of Devonian pleuracanths are, as far as I know them, based on very fragmentary and systematically doubtful material.

The earliest faunas in which adequate material is available are those of Devonian fresh water fishes Here every advance in our knowledge demonstrates increasingly the great similarity between the two continents. At one time this similarity was masked by the nomenclature. This is still true to a degree, and there are many rare, obscure, or doubtful genera reported only from one or the other of the two continents. It appears, however, that in almost every instance a form abundant in one continent can be proved present in the other. The crossopterygian *Eusthenopteron* is a case in point. This is common in the Upper Devonian of Quebec, but was thought to be a diagnostic American form, absent in Europe. During the last decade, however, it has been positively identified in collections from the "Old Red" of both Scotland and the Baltic region (Westoll 1937; Jarvik 1937).

American Mississippian continental vertebrates are inadequately known; our next opportunity for comparison comes in the Pennsylvanian, where both Steen and the writer have studied with some care the coal-swamp tetrapods of both continents. Both of us have been strongly impressed by the remarkable similarities of the faunas. Many of the genera are identical, and certain of the differences remaining are attributed in part to inadequate material and to the fact that the best faunas available on either side of the Atlantic (Linton, Nyran) are somewhat different in age (Romer 1930, Steen 1931, etc., cf. Westoll 1944, pp. 105-108). Westoll (1944) has studied the Pennsylvanian fish faunas of the two continents with particular reference to the Haplolepidae. His careful analysis of the situation leads him to believe that very free intermigration must have been possible, and that the most satisfactory explanation is afforded by the hypothesis of continental drift.

In the Permian, comparison can be made only in the earliest part of the period, for continental vertebrates disappear from the American record after the deposition of the lower Clear Fork. The faunas of the American redbeds and those of the Rothegende were once thought to differ markedly. This, however, was due in part to inadequate knowledge of the faunas (particularly that of Europe) and in part to the fact that the type of sediments tended to the preservation of animals of different sorts in the two regions—small pool-dwellers in Europe, more of the larger and more terrestrial types in America. Increasing knowledge of the faunas tends to emphasize

the basic similarity of the two regions (cf. Romer 1925, etc.). However the resemblances here are somewhat less marked than in the late Carboniferous. In some cases identical genera are present; in others, we are sure that although closely related forms were present, the genera were distinct. There is hence less evidence for direct contemporaneous connection of the continental areas. But, even so, it may be remarked that the comparisons between the Texas redbeds fauna and that of central Europe, which even on a Wegnerian basis cannot have been less than 2,000 miles apart, are just as close as they are between the Texas fauna and that of the supposedly contemporaneous Abo fauna of New Mexico, only a few hundred miles away!

Consideration of Paleozoic vertebrate faunas as a whole thus leads to the conclusion that during this time North America and Europe were connected in such fashion that extremely free and relatively rapid faunal interchange was possible among the rapidly evolving vertebrate groups. Discussion of the type of connection involved is handicapped by the fact that until Middle Permian times we know almost nothing of the vertebrates of any regions except Europe and North America. It is possible that the similarities between these two continents were due merely to a condition in the Paleozoic in which vertebrate faunas were similar throughout the world, with extremely easy interdiffusion between all areas, by way of normal intercontinental connections and that the faunas of other regions, if known, would also be similar in composition. This assumption cannot at present be proved or disproved, but it assumes, because of the rapidity of the evolution undergone by many of the groups concerned, an ease of intermigration difficult of belief. The available evidence strongly suggests (although it does not prove) intimate and direct connection in the later Paleozoic between Europe and North America, whether by apposition of the two continental masses under a Wegnerian interpretation or, with fixed continental positions, by a substantial North Atlantic bridge since destroyed.

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UPPER DESMOINESIAN FUSULINIDS.

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ABSTRACT Three species of fusulinids from the upper part of the Desmoinesian series are described and illustrated as *Fusulina? inconspicua* Girty, *F.? rickerensis*, n. sp., and *F.? arenaria*, n sp. These forms are somewhat intermediate in nature between typical species of *Fusulinella* and typical species of *Fusulina* They are referred with question to *Fusulina*, but it is realized they may be descendants of a species of *Fusulinella* and are not generically related to any species of *Fusulina* For direct comparisons, topotype specimens of the genotypes of *Fusulinella* and *Fusulina* are described and illustrated.

THE Desmoinesian rocks of North America generally are referred to paleontologically as the Zone of *Fusulina*. Species of this genus are known from throughout the Desmoinesian, and no species of the genus is known from American rocks not of Desmoinesian age. Many American species of the genus *Fusulina* Fischer-de-Waldheim seem to have short stratigraphic ranges, and they are useful for detailed stratigraphic correlations.

The upper part of the Derryan rocks of North America generally are referred to paleontologically as the Zone of *Fusulinella*, for a closely related group of species of the genus *Fusulinella* Moller more or less predominates the fusulinid fauna of that part of the stratigraphic section. The genus *Fusulinella* has not been found in rocks of lower Derryan age, but species of the genus have been reported from the lower part of the type section of the Desmoinesian series of Iowa,(1)* and from the Desmoinesian of Ohio,(2) New Mexico(3) and Illinois.(4) However, no species of *Fusulinella* has been reported from the middle or upper part of the American Desmoinesian. Many species of the genus *Fusulinella* seem to have short stratigraphic ranges, and they are useful for detailed stratigraphic correlations. Therefore, representatives of both *Fusulina* and *Fusulinella* have assumed considerable importance in the correlation and zonation of lower Pennsylvanian rocks.

Several species of fusulinids of somewhat uncertain generic affinities have been discovered in the upper part of the Desmoinesian rocks in the Mid-Continent region. They seem to be somewhat intermediate in nature between the genotype of

* Numbers in parentheses refer to the References at the end of the paper

Fusulinella, *F. bocki* Moller, and the genotype of *Fusulina*, *F. cylindrica* Fischer-de-Waldheim, although they occur stratigraphically near some of the biologically most highly developed American species of *Fusulina*. As mentioned above, however, typical species of *Fusulinella* are not known in America above the lower part of the Desmoinesian. The structural features of these forms suggest that they are biologically highly developed descendants of a species of *Fusulinella* and not of a species of *Fusulina*.

Although these species are not closely similar to either the genotype of *Fusulina* or the genotype of *Fusulinella*, I prefer to refer them for the present with question to the genus *Fusulina*. I realize that they possibly are not closely related to any species of that genus.

One of these species was described by Girty(5) in 1911 from the lower part of the Wewoka formation of Oklahoma as *Fusulina inconspicua* Girty. Another species from the Ricker limestone of Texas is being described below as *Fusulina? rickerensis*, n. sp., and still another from the upper part of the Boggy formation of Oklahoma is being described below as *Fusulina? arenaria*, n. sp.

In many respects these forms resemble some of the highly elongate species of *Fusulinella* from the upper part of the Derryan, such as *F. prolifica* Thompson. In other respects they resemble some of the primitive species of the genus *Fusulina* from the lower part of the Desmoinesian, such as *F. carmani* (Thompson). Still in other respects they have characteristics similar to those of species of *Fusulina* from the upper Desmoinesian. As so many species of both *Fusulinella* and *Fusulina* are now recognized to be of great value in the correlation and zonation of lower Pennsylvanian rocks, it seems important that the occurrence of these questionable species of *Fusulina* in the upper part of the Desmoinesian should be emphasized.

A general trend in evolution can be recognized among species of *Fusulinella* during Derryan time. The stratigraphically older species of this genus have spirotheca with thin diaphanotheca, well developed chomata and tectoria, and practically unfluted septa. Many species of *Fusulinella* in upper Derryan and lower Desmoinesian rocks have spirotheca with thicker diaphanotheca but relatively thinner tectoria, more highly fluted septa, and less massive chomata. The primitive species of *Fusulina* in

basal Desmoinesian rocks resemble upper Derryan and lower Desmoinesian species of *Fusulinella* in most respects except that their septa are more highly fluted across the central part of the shell. The general trend in the evolution of *Fusulina* during Desmoinesian time is an increase in the height and intensity of the septal fluting, a general thickening of the diaphanotheca, a reduction in the thickness of the tectoria, and a reduction in the height and width of the chomata. In some highly developed species of *Fusulina*, fillings of dense calcite deposits occur in the axial region.

All three of these somewhat questionable species have thin tectoria, poorly developed chomata, and septa that are fluted throughout the length of the shell. However, the fluting of the septa across the central one-half of the shell is low. In most of these forms the septa are not brought in contact by the fluting in the central part of the shell. Axial fillings are fairly well developed in one of them, *F. arenaria*. Although these species resemble *Fusulinella* somewhat closely in regard to septal fluting, they resemble *Fusulina* in regard to spirothecal and chomata development and in that the septa are fluted to some degree across the central part of the shell.

If these upper Desmoinesian fusulinids are in reality descendant from a species of *Fusulinella* rather than from a species of *Fusulina*, it seems obvious that they have taken a trend in evolution similar to that taken by the genus *Fusulina*. It should be pointed out that the ancestral form of the Missourian genus *Triticites* is not known. It is possible that these upper Desmoinesian species of *Fusulina*? are ancestral to *Triticites*.

All three of these species are exceedingly abundant in thin widespread zones in upper Desmoinesian rocks of the Mid-Continent region. They occur in sandstones or arenaceous limestones and are seldom found in pure limestones. Further study, however, may demonstrate that this lithologic association is not characteristic of the group. *F. arenaria* occurs in slightly calcareous sandstone in the upper part of the Boggy formation, and the type specimens are concentrated in elongated zones that seem to be troughs of ripple marks. Although highly developed species of typical *Fusulina* occur stratigraphically near these forms, they are seldom found in direct association with them. A few specimens of a highly developed species of *Fusulina* (Plate 2, Fig. 10) is associated with *F.*? *inconspicua* in the Wewoka formation, but no typical species of *Fusulina*

has been found directly associated with the other two forms described below.

For a more detailed comparison of these three questionable species of *Fusulina* with the type species of the genera *Fusulina* and *Fusulinella*, I am illustrating and giving below detailed descriptions of topotype specimens of the genotypes of both *Fusulina* (Plate 1, Figs. 12-14) and *Fusulinella* (Plate 1, Fig. 15).

Description of topotype specimens of Fusulina cylindrica Fischer-de-Waldheim:—Shell small, elongate subcylindrical, straight to slightly curving; with essentially straight to broadly arcuate axis of coiling, horizontal to slightly sloping lateral slopes, and bluntly pointed to rounded poles. Mature specimens of about five volutions measure 5.5 to 6.0 mm in length and 1.3 to 1.6 mm. in width, giving a form ratio of 1 · 3.6 to 1 · 4.8. The general development of the shell of this species varies considerably among different specimens. In some, the shell retains essentially the same shape throughout growth. In others, as maturity is approached, the shell becomes broadly curved, the poles are greatly extended, and the form ratio of outer volutions becomes small. The latter type is similar to the illustrated axial section. The form ratios of the first to the fifth volution of the illustrated axial section are 1 : 2 3, 1 : 3.1, 1 · 5 0, 1 : 5.4, and 1 : 4.8, respectively. The form ratios of the first to the fourth volution of another topotype specimen are 1 : 2.2, 1 : 2.6, 1 : 3.0, and 1 : 3.6, respectively.

The spirotheca is composed of a tectum, a relatively thick diaphanotheca, and thin upper and lower tectoria. The upper tectorium is not recognizable in all parts of the inner volutions. Dunbar and Henbest (4) recognized fine alveoli or pores in the spirotheca of topotype specimens of this species, and what appears to be alveoli or pores are poorly developed in the fifth volution of the illustrated sagittal section. The thicknesses of the spirotheca in the first to the fifth volution of the illustrated sagittal section measure 13.6, 20.4, 17.0, 20.4, and 23.8 microns, respectively.

The proloculum is spherical to slightly irregular in shape, and its outside diameter measures about 200 to 250 microns. The shell expands gradually, and the heights of the first to the fifth volution immediately over the tunnel in the illustrated sagittal section measure 75, 102, 129, 143, and 150 microns, respectively. Poleward from the tunnel, the heights of the chambers increase gradually.

The septa are thin. They are composed of the downward deflection of the tectum and diaphanotheca of the spirotheca of the preceding chamber and anterior clear layer that is continuous with the diaphanotheca of the spirotheca of the following chamber. However, this anterior clear layer decreases in thickness downward from the top of the septa. Thin and discontinuous layers of tectoria partly cover the septa in the inner volutions. Poleward from the tunnel, the septa decrease in thickness. The septa are fluted throughout the length of the shell. In the polar one-third of the shell, the fluting extends completely to the tops of the chambers, and there the adjacent septa are brought in contact by the fluting for more than one-half the heights of the chambers. Immediately over the tunnel, however, the fluting of the septa forms closed chamberlets for only about one-half the heights of the chambers.

The tunnel is essentially straight. In the fourth volution of mature specimens, the tunnel is slightly more than one-half as high as the chambers. The tunnel angle is relatively large, and in the second, third, and fourth volutions of the figured axial section it measures 40, 47, and 45 degrees, respectively. Narrow and irregular chomata are developed throughout the shell. Dark-colored deposits essentially fill the chambers in the extreme polar regions of the second to the fourth volution.

Fusulina cylindrica is believed to be biologically a highly developed species of the genus. It has an unusually thick diaphanotheca, its septa are more highly fluted than in many of the species of *Fusulina*, its tectoria are thinner than in many species of this genus, its chomata are more poorly developed than in many species of the genus, and it has more dense deposits in the axial regions than in most species of the genus. The shell development of *F. cylindrica* is closely similar to that of upper Desmoinesian American species, such as *F. eximia* Thompson and *F. lonsdalensis* Dunbar and Henbest. These two species are stratigraphically among the youngest known American representatives of the genus *Fusulina*, and they are believed to be biologically among the most highly developed species of the genus in America.

Description of topotype specimens of Fusulinella bocki Möller:—Shell minute, short, inflated fusiform; with bluntly pointed poles, steep convex lateral slopes, and essentially straight axis of coiling. The extreme polar region of the fifth and sixth volutions is slightly extended, and the lateral slopes near the poles tend to become slightly concave. The illustrated

axial section originally contained at least six volutions, but the outer part of the last volution was partly destroyed during fossilization. The remaining five volutions measure about 2.2 mm. in axial length and 1.25 mm. in width; giving a form ratio of about 1:1.8. The inner three volutions are ellipsoidal in shape, with broadly rounded poles. In the fourth and fifth volutions the poles become slightly extended and more narrowly rounded. The form ratios of the first to the fifth volution of the illustrated axial section are about 1.1.4, 1:1.7, 1·1.6, 1:1.6, and 1:1.7, respectively. As is obvious from these figures, the shell retains essentially the same shape throughout growth of the individual.

The spirotheca is composed of a thin tectum, a thin diaphanotheca, and relatively thick upper and lower tectoria. The diaphanotheca is not clearly recognizable in the inner two volutions, but it can be observed with ease in the outer volutions. Both upper and lower tectoria are recognizable throughout all parts of the shell in the specimen I am studying. However, the chomata are so heavy and broad that the upper tectoria can not be differentiated in most parts of the specimen. The thicknesses of the combined tectum and diaphanotheca in the third and fourth volutions of the illustrated axial section are 8.5 and 10.2 microns, respectively. The thicknesses of all four layers of the spirotheca immediately over the tunnel in the second to the fifth volution of this specimen are about 30, 44, 60, and 62 microns, respectively.

EXPLANATION OF PLATE 1.

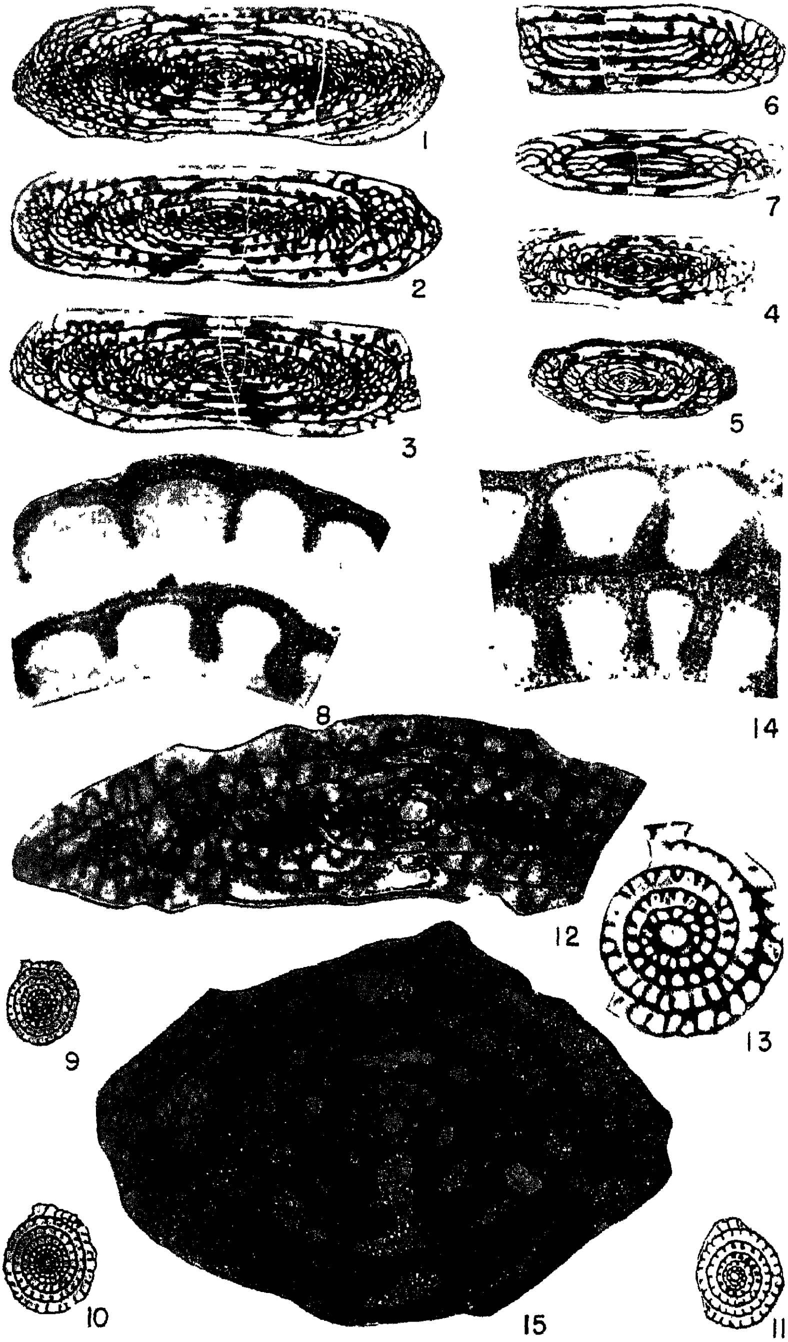
All illustrations on this plate are unretouched photographs

Figs. 1-4, 6-11, *Fusulina? arenaria* Thompson, n sp. 1, Axial section of the holotype, x10; 2-4 axial sections of paratypes, x10; 6, 7, tangential sections of paratypes, x10; 8, enlarged portion of the sagittal section of Fig 11 that shows the structure of the spirotheca, x100; and 9-11, sagittal sections of paratypes, x10. Upper Boggy formation, Oklahoma.

Fig. 5. *Fusulina? rickerensis* Thompson, n. sp Axial section of a paratype, x10.

Figs 12-14. *Fusulina cylindrica* Fischer-de-Waldheim. 12, Axial section of a topotype, x20; 13, sagittal section of a topotype, x20; and 14, enlarged portion of the outer two volutions of the illustrated sagittal section of Fig. 13 that shows the thick "porous" diaphanotheca, tectum, thin discontinuous upper and lower tectoria, and the structure of the septa, x100. Mjatschkowo limestone, Mjatschkowo, Russia. State Univ., Iowa, No. 1617.

Fig. 15 *Fusulinella bocki* Moller. Axial section of a topotype specimen that shows the four layers of the spirotheca and the massive chomata, x40 Kresty, Government of Tver, Russia Stanford Univ. Paleo Type Coll. No 5954.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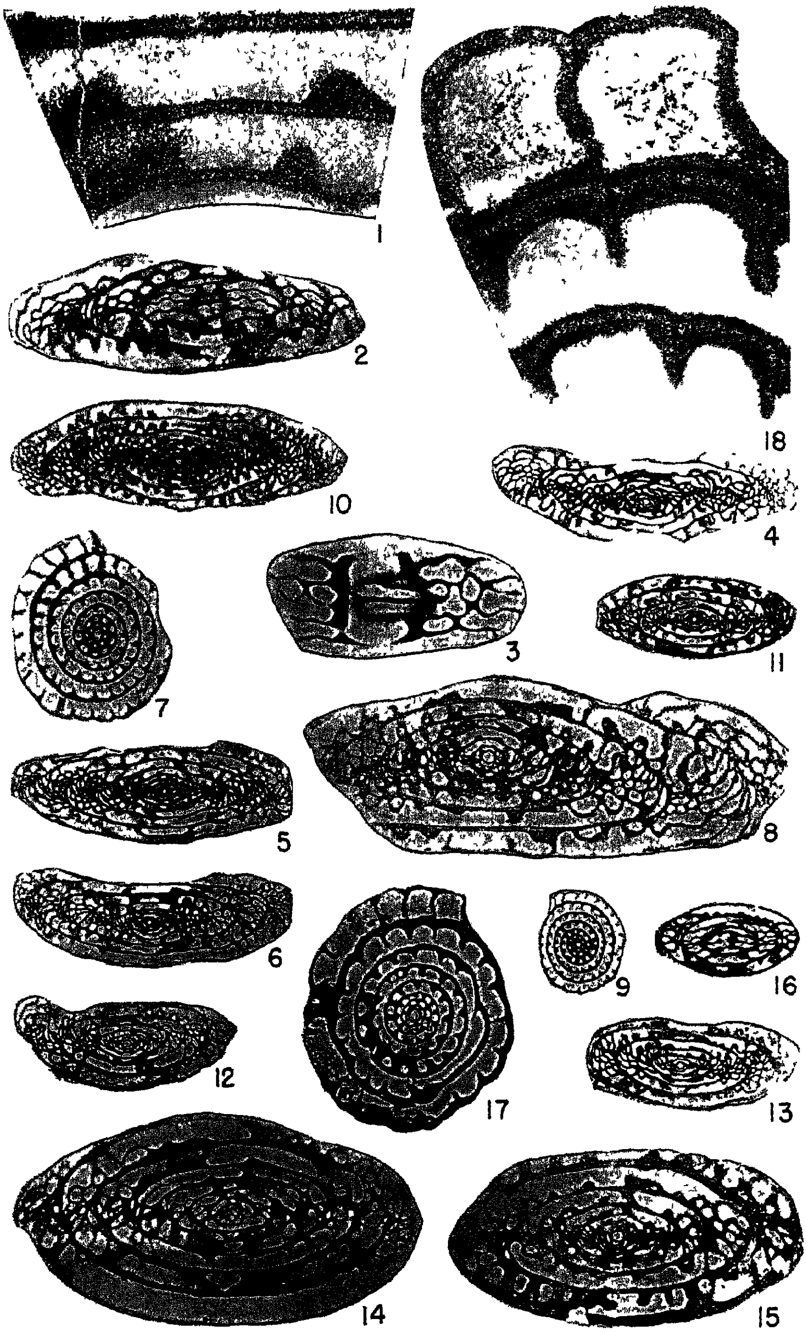
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The proloculum is minute in size and spherical in shape. Its outside diameter measures about 112 microns. The shell expands uniformly, and the heights of the chambers immediately over the tunnel in the first to the fifth volution measure about 44, 78, 119, 165, and 222 microns, respectively.

The septa are only slightly fluted in the polar regions, but they seem to be unfluted in the central part of the shell

The tunnel is narrow, relatively high, and essentially straight. The tunnel angles of the second to the fifth volutions measure about 22, 18, 18, and 24 degrees, respectively. The chomata are high and broad. The tunnel side of the chomata is essentially vertical but the poleward slope is low, and the chomata extend more than half the distance to the poles in the inner four volutions of specimens of six volutions. In the fifth volution, the chomata are high and symmetrical and are about twice as broad as high.

The weak fluting of the septa, massive and broad chomata, and general shape of the shell of *Fusulinella bocki* are more closely similar to *Fusulinella fittsi* Thompson from the lower part of the Derryan Atoka formation of Oklahoma than to any other described American species. However, *F. bocki* obviously is more highly developed biologically than *F. fittsi*. *F. bocki* has a well defined diaphanotheca, but such is not observable in *F. fittsi*. Several undescribed species of *Fusulinella* from the Derryan of New Mexico, however, show a biological development very closely similar to that of *F. bocki*.

EXPLANATION OF PLATE 2

All illustrations on this plate are unretouched photographs.

Figs. 1-9. *Fusulina? inconspicua* Girty. 1, Enlarged portion of an axial section that shows the structure of the spirotheca, x100; 2, 3, tangential sections, x20, 4-6, axial sections, x10, 7, sagittal section x20, 8, axial section, x20, and 9, sagittal section, x10 Lower part Wewoka formation, Oklahoma

Fig 10. *Fusulina* sp. Typical species of the genus associated with the above illustrated specimens of *Fusulina? inconspicua* Girty. Lower part Wewoka formation, Oklahoma

Figs. 11-18. *Fusulina? rickerensis* Thompson, n. sp. 11-13, Axial sections of paratypes, x10; 14, axial section of a paratype, x20; 15, axial section of the holotype, x20; 16, tangential section of a paratype that shows the nature of the septal fluting, x10; 17, sagittal section of a paratype, x20; and 18, enlarged portion of the same specimen as Fig 17 that shows the structure of the spirotheca, x100. Ricker limestone, Ricker, Texas.

By comparison of the above descriptions and the accompanying illustrations of topotype specimens of the genotypes of *Fusulina* and *Fusulinella* with the illustrations and descriptions of the three species described below, *F.? inconspicua*, *F.? arenaria*, and *F.? rickerensis*, it seems logical to refer these species to the genus *Fusulina* rather than to *Fusulinella*. It is realized, however, that they are not "typical" of the genus *Fusulina*. For instance, their septa are not nearly as highly or intensely fluted as are those of *Fusulina cylindrica*. On the other hand, their septa are much more intensely fluted than are those of *Fusulinella bocki*. Also, their chomata are not as well developed, their shells have different shapes, and their tunnels expand much more rapidly than do those of *F. bocki*.

Thanks are extended to Dr. A. K. Miller and Dr. Myra Keen for the loan of specimens; to Mr. E. N K. Waering for collections; and to Dr. C. O Dunbar for criticizing the manuscript.

FUSULINA? INCONSPICUA Girty

Plate 2, Figs 1-9

Fusulina inconspicua, Girty, *1911*, New York Acad. Sci Annals, 21, 120, 121.—Girty, *1915*, U. S. Geol Survey, Bull. 544, 15, 16, pl. 1, figs. 1-8.

Girty's original types of this species were obtained from a thin zone near the base of the Wewoka formation in the southwest corner of sec. 32, T. 5 N, R. 8 E., Colgate quadrangle, Oklahoma. The accompanying illustrations and description are based on specimens collected from a calcareous sandstone in the lower part of the Wewoka formation near the center of the NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 6, T. 3 N., R. 7 E., Oklahoma.

Shell small, elongate, cylindrical and subcylindrical at maturity, with straight axis of coiling and bluntly pointed to rounded poles. Four mature specimens contain six volutions and they each measure about 1.1 mm. in width and 4.1 mm. in length, giving a form ratio of 1:3.6. The poles of the inner three volutions are sharply pointed, but the poles of the outer volutions gradually become more broadly rounded. The average form ratios of the first to the sixth volution of two specimens are 1:1.4, 1:1.7, 1:2.8, 1:3.5, 1:3.7, and 1:3.6, respectively.

The proloculum is minute in size, and its outside diameter measures 75 to 116 microns in nine specimens, averaging 95 microns. The heights of the first to the sixth volution of four

specimens are 32 to 50, 43 to 71, 61 to 100, 89 to 107, 107 to 132, and 143 to 150 microns, respectively. The average heights of the first to the sixth volution of these same specimens are 39, 56, 77, 97, 119, and 145 microns, respectively.

The spirotheca is thin, and it is composed of a tectum, a diaphanotheca, and upper and lower tectoria. The thicknesses of the spirotheca in the third to the sixth volution of four specimens measure 14, 18 to 19, 20 to 25, and 25 to 36 microns, respectively; averaging 14, 18, 23, and 30 microns, respectively. The averages of the septal count of the first to the sixth volution of several specimens give 7, 10, 13, 18, 20, and 24. The septa are narrowly and highly fluted in the extreme polar regions, but across the middle part of the shell the septa are very broadly wavy and the fluting is confined to the lower portion of the septa.

The tunnel is low and broad, and its path is only slightly irregular. The averages of several measurements for the tunnel angle give 27 degrees in the third volution, 40 degrees in the fourth volution, 50 degrees in the fifth volution, and 65 degrees in the sixth volution. Chomata are developed throughout the shell They average about one-third the height of the chambers, and they are slightly wider than high.

Discussion.—This species resembles somewhat closely *F.? rickerensis* and *F.? arenaria*. It differs from the former species especially in that it has a smaller form ratio at maturity, it is larger in size, and it has a different general shell outline. It differs from the latter species especially in that its form ratio is larger, it is larger at maturity, and it has a different shell shape at maturity.

Dr. C. O. Dunbar has examined Girty's type specimens and assures me they are conspecific with the specimens I am studying.

Occurrence—Girty's types came from near the base of the Wewoka formation in sec. 32, T. 5 N., R. 8 E., Oklahoma. The specimens on which the above description and accompanying illustrations are based came from the lower part of the Wewoka formation near the center of the NE¼ NE¼ sec. 6, T. 3 N., R. 7 E., Oklahoma, where they are associated with a highly developed species of the genus *Fusulina* (Plate 2, Fig. 10).

Types—Girty's type specimens presumably are deposited in the U. S. National Museum. The illustrated specimens of this report are deposited at the University of Kansas.

FUSULINA? RICKERENSIS Thompson, n. sp.

Plate 1, Fig. 5; Plate 2, Figs 11-18.

Shell small, sub-cylindrical to ellipsoidal in shape; with straight axis of coiling, and rounded to very bluntly pointed poles. The inner three volutions have sharply pointed poles, but the poles become more broadly rounded in the outer volutions. Mature specimens of six to seven volutions measure 1.0 to 1.6 mm. in width and 2.9 to 3 5 mm. in length. The form ratio of mature specimens is 1:2.4 to 1:2.8, averaging 1:2.6 for five typical specimens. The form ratios of the first to the fifth volution of five specimens are 1:1.2 to 1·1.8, 1:1.6 to 1:2.8, 1·2.0 to 1:2.8, 1·2.3 to 1:2.9, and 1·2 5 to 1:2.9; averaging 1:1.5, 1:2.2, 1:2.6, 1:2.7, and 1:2.7, respectively.

The proloculum is minute, and its outside diameter measures 83 to 116 microns, averaging about 95 microns for seven specimens. The heights of the first to the sixth volution of seven typical specimens measure 32 to 36, 36 to 50, 50 to 86, 79 to 114, 107 to 157, and 136 to 196 microns, respectively; averaging 34, 44, 68, 96, 130, and 181 microns, respectively. The outermost volution of one specimen of seven volutions is 193 microns in height. As shown by these figures, the shell expands at an essentially uniform rate.

The spirotheca is composed of a tectum, a diaphanotheca, and upper and lower tectoria. The lower tectorium is thin and of essentially uniform thickness, but the upper tectorium varies considerably in thickness in different parts of the shell. Therefore, detailed measurements of the thickness of the spirotheca of any one specimen could be considered only a rough approximation of the species. The averages of the thicknesses of the spirotheca, measured over the tunnel, of the third to the sixth volution of seven typical specimens are 13, 19, 30, and 35 microns, respectively.

The septa of this species are highly fluted only in the extreme polar regions. Near the middle part of the shell the septa are straight to broadly wavy. However, the basal part of the septa are very broadly fluted even immediately over the tunnel of the outer volution of mature specimens. The septal counts of the first to the six volution of three specimens are 7 to 8, 8 to 10, 10 to 12, 11 to 14, 15 to 17, and 21, respectively; averaging 8, 9, 11, 13, 16, and 21, respectively.

The tunnel is low and broad. The tunnel angles in the third, fourth, fifth, and sixth volutions of five typical specimens meas-

ure 29 to 38, 27 to 42, 32 to 45, and 32 to 55 degrees, respectively; averaging 33, 36, 40, and 46 degrees, respectively. Chomata are well developed throughout the shell, and they are of essentially uniform shape and size throughout the shell. As can be seen in the accompanying illustrations, the chomata are about one-half as high as the chambers and they are slightly broader than high.

Discussion.—*F.? rickerensis* is more closely similar to *F.? inconspicua* and *F.? arenaria* than to any other described species, but it is smaller at maturity, has a larger form ratio at maturity, and has a different shell type at maturity than either of these species.

Occurrence.—The type specimens on which the above description is based were obtained from the highly arenaceous limestone near the depot at Ricker, Brown County, Texas. This limestone is commonly known as the "Ricker limestone" and occurs immediately below the Ricker conglomeratic sandstone; that is, in the lower part of Drake's(7) Ricker bed.

FUSULINA? ARENARIA Thompson, n. sp.

Plate 1, Figs 1-4, 6-11

Shell small, elongate, cylindrical to sub-cylindrical in shape; with broadly rounded poles and straight to broadly curving axis of coiling. Mature specimens of seven to eight volutions measure 5.5 to 7.3 mm. in length and 1.5 to 1.8 mm. in width. The form ratio of mature specimens is 1 : 3.7 to 1 : 4.9, averaging 1 : 4.1 for five typical specimens. The poles of the inner five volutions are sharply pointed but beyond the fifth volution the poles gradually become rounded, and at maturity the poles are very broadly rounded. The form ratio decreases with growth of the shell. For five typical mature specimens the form ratios of the first, second, third, fifth, and seventh volutions average 1 : 1.8, 1 : 3.1, 1 : 3.6, 1 : 4.4, and 1 : 4.1, respectively.

The proloculum is minute, and its outside diameter measures 91 to 142 microns, averaging about 125 microns for nine typical specimens. The heights of the first to the eighth volution of eight typical specimens measure 39 to 47, 43 to 71, 57 to 94, 79 to 121, 107 to 150, 121 to 164, 154 to 179, and 143 microns, respectively; averaging 44, 56, 73, 99, 124, 145, 164, and 143 microns, respectively. As is indicated by these figures, the shell is tightly coiled and expands uniformly.

The spirotheca is exceedingly thin; it is composed of four layers, a tectum, a diaphanotheca, and upper and lower tectoria. However, the lower tectorium is extremely thin throughout the shell. The average thicknesses of the spirotheca, measured along the line of the tunnel, in the third to the eighth volution of eight typical specimens are 14, 21, 20, 26, 27, and 21 microns, respectively. The tectoria of the spirotheca vary markedly in thickess in different specimens and in different parts of the same volution of the same specimen. Therefore, the above figures have little significance other than to indicate that the spirotheca is thin and that it decreases in thickness in the outer one or two volutions of mature specimens. The diaphanotheca increases in thickness slightly in the outer three volutions, but the tectoria decreases in thickness in that part of the shell.

The septa are thin. The septal counts in the first to the seventh volution of three typical specimens give 7 to 8, 11 to 12, 12 to 16, 16 to 19, 18 to 22, 22 to 27, and 29, respectively; averaging 8, 12, 14, 17, 20, 24, and 29, respectively The septa are narrowly fluted in the extreme polar regions, and there the fluting forms chamberlets near the base of the chambers. Toward the tunnel the septa become very broadly fluted, and in the central two-thirds to one-half of the shell the fluting does not bring adjacent septa in contact. Immediately over the tunnel the septa are broadly wavy.

The tunnel is low and wide. The tunnel angle is large. The tunnel angles in the third to the eighth volution of six specimens measure 22 to 43, 41 to 53, 43 to 62, 43 to 66, 45 to 70, and 83 degrees, respectively; averaging 35, 47, 54, 54, 56, and 83 degrees, respectively. Chomata are well developed throughout the shell, and they are about two and one-half times as wide as high. The chomata are very steep to overhanging adjacent to the tunnel, and they are about one-half as high as the chambers. Axial fillings are developed in the second to the seventh volutions, but are best developed in the fourth volution of specimens of eight volutions.

Discussion.—This species is larger at maturity, has a smaller form ratio at maturity, and has a different shell shape at maturity than *F.? rickerensis* or *F.? inconspicua*.

Occurrence.—This species is extremely abundant in the upper part of the Boggy formation in a highly calcareous fusulinid-bearing sandstone about 20 feet above the "Campophyllum" limestone. The specimens are concentrated in what seem to be

troughs of ripple marks in the sandstone. I have collections from Mayer Ranch, near the center of sec. 7, T. 3 N., R. 8 E., Pontotoc County, Oklahoma, and at the same horizon in the center of sec. 12, T. 3 N., R. 7 E., Pontotoc County, Oklahoma. The above specific description and all of the accompanying illustrations are based on specimens from the latter locality.

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MAGMATIC DIFFERENTIATION IN GABBRO SILLS NEAR ASHLAND, OREGON.

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ABSTRACT Two gabbro sills with dioritic facies, intruding the Eocene Umpqua sediments near Ashland, Oregon, show progressive changes of mineral composition, texture, and density in vertical sections A relative concentration of heavy, early formed minerals in the lower part and of light minerals of hydrothermal origin, pegmatitic schlieren, and vugs in the upper part are taken as evidence that after emplacement differentiation occurred by crystal settling and possibly by volatile transfer.

INTRODUCTION.

THE rocks described in this paper lie in the northern part of sec. 11, T 39 S, R 7 W Willamette Base and Meridian, Jackson County, Oregon. The area is traversed by Walker Creek, a tributary of Bear Creek. The latter flows northwest through the Ashland-Medford valley and is a tributary of the Rogue River. The rocks under consideration crop out on the northwest slope of the valley about three miles east of the town of Ashland.

The writer wishes to thank Dr. Gordon A. Macdonald of the U. S. Geological Survey and Prof. A. O. Woodford of Pomona College for reading and criticizing the manuscript of this paper.

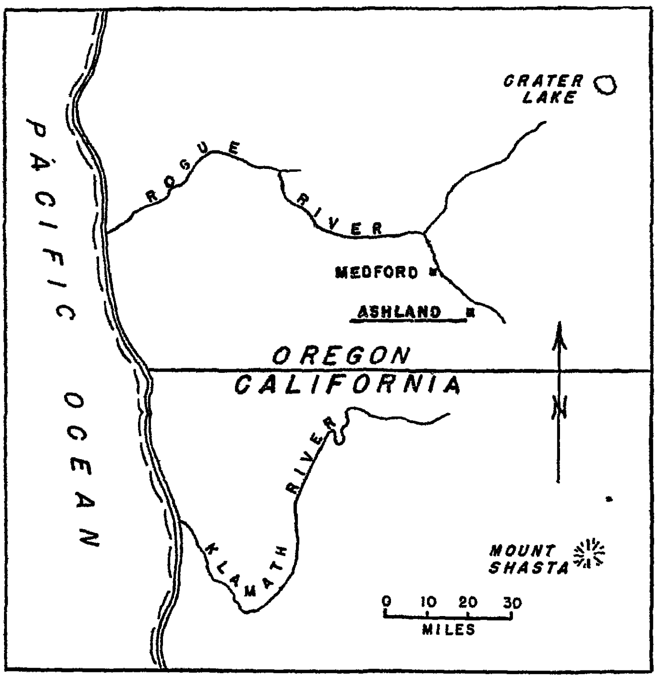
REGIONAL GEOLOGY.

The geology of the Ashland-Medford valley has been mapped and described by F. G. Wells.[1] It is essentially a strike valley eroded in soft sediments striking northwest and dipping northeast about 20°. The Siskiyou Mountains bordering the valley on the southwest are composed of Mesozoic intrusives and older metamorphosed sedimentary and volcanic rocks. Cretaceous Chico sandstone and conglomerate lie in an irregular band along the southwest margin of the valley. Overlying these beds are the soft sediments of the Eocene Umpqua formation which compose the floor of most of the Ashland valley. The formation is chiefly composed of sandstone, but shale and conglomerate predominate locally.

The eastern boundary of the Umpqua beds follows along the foothills of the Cascade Mountains, which form the northeast

side of the valley. The mountains are made up largely of the Western Cascade lavas, although pyroclastic rocks predominate at the base and are interbedded with upper Umpqua sediments. All strike northwest and dip northeast about 20°. The volcanic rocks of the Western Cascades range in age from Eocene to Miocene.

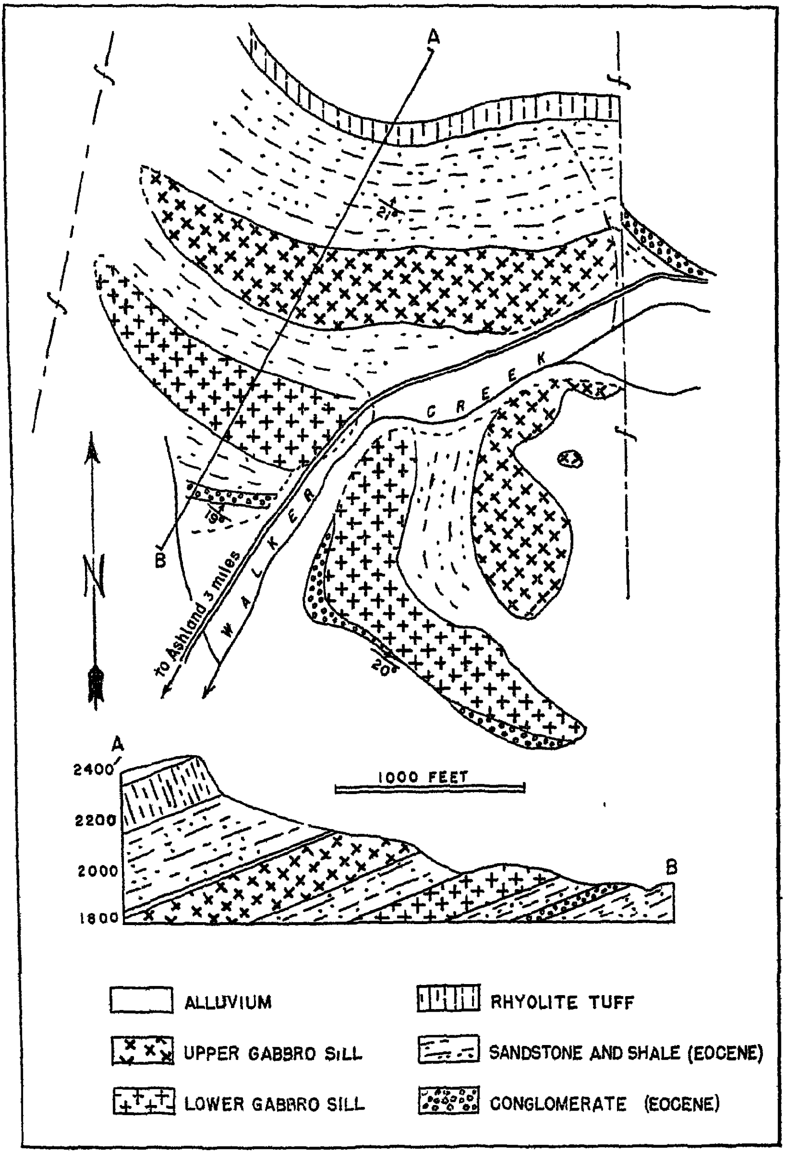
A large number of stocks, sills, and dikes mostly of dioritic composition intrude the Umpqua and lower Cascade rocks. The remainder of this report is chiefly concerned with the description of two of these intrusions. Similar intrusions have been described by Wells and Waters.[2]



1. Location map of Northern California and Southern Oregon.

LOCAL GEOLOGY.

The area shown in Fig. 2 consists of a series of Umpqua sediments which have the usual regional attitude. They are intruded by two sill-like bodies of gabbroic and dioritic composition. The sediments are dominantly medium grained, well-bedded sandstone with local conglomerate lenses. A thick



2. Geologic map and section of small area three miles east of Ashland, Oregon.

massive bed of rhyolite tuff represents the lower Cascade volcanic rocks.

Each sill has approximately the same average thickness, 140 feet. Both appear to be entirely concordant intrusions with sharp contacts against the sediments. They are truncated to the east by a vertical transverse fault. Indirect evidence suggests a similar termination to the northwest, although exposures in this area are poor and it may be that the intrusions merely taper off and thus have a laccolithic form. However, in the absence of sufficient evidence the term "sill" will be used in the following discussion.

PETROGRAPHY.

At places the sills appear to be uniform in texture from top to bottom, excepting narrow chilled borders which are finer grained. The texture of the main part of the sills in such sections is medium hypautomorphic granular, the composition gabbroic.

Elsewhere vertical sections show a systematic variation in texture and composition. At the base of such a section is a chilled zone one to three feet thick, which is composed of a dense, gray porphyritic rock of basaltic to andesitic composition. Phenocrysts of augite, hypersthene, and plagioclase (An_{60}) are set in a holocrystalline groundmass of plagioclase laths (An_{45}), augite granules, and iron ore. The plagioclase phenocrysts amount to nearly one-fourth of the rock.

Directly above the chilled zone and separated from it by a short zone of transition is a zone of dark gray gabbro with medium hypautomorphic granular texture. Its chief minerals are plagioclase and augite. Minor constituents are chlorite, hypersthene, and iron ore. The plagioclase is fairly fresh. Most of that which is more than 25 feet above the base is zoned with core of An_{60} and rims which decrease in anorthite content with increasing height above the base. The range in the rims is from An_{45} to An_{38}.

About 50 to 75 feet above the base of the sill the gabbroic zone gives way to a rock of dioritic composition by a gradual decrease in the ratio of femic to salic minerals and accompanying textural changes. The dioritic phase of the sills is light gray and in most places slightly coarser in grain than the gabbroic phase. The former is characterized in the hand

specimen by the prismatic habit of the chief minerals, feldspar and hornblende. Fine-grained specimens have a true diabasic texture, whereas coarse facies of the rock are nearly pegmatitic and have hornblende prisms 1 to 2 cm. in length. Such coarse-grained facies occur in irregular schlieren suggestive of auto-injection. The central part of these areas may be nearly or entirely devoid of dark minerals. Similar pegmatitic schlieren have been noted in other differentiated intrusives. Walker[3] has described such features, which he explains as the result of local concentration of volatiles squeezed out by crystallization.

Textural features seen under the microscope are equally distinctive. Micropegmatite is present in all thin sections of the upper zone and in some slides it amounts to more than 20 per cent by volume. It consists of the usual regular intergrowth of quartz and feldspar. The feldspar has been almost entirely altered to a fine aggregate of cloudy, isotropic material, probably zeolites. It is impossible to determine the original composition of the feldspar. A few unaltered remnants were found to have a refractive index below that of quartz, suggesting orthoclase or sodic plagioclase.

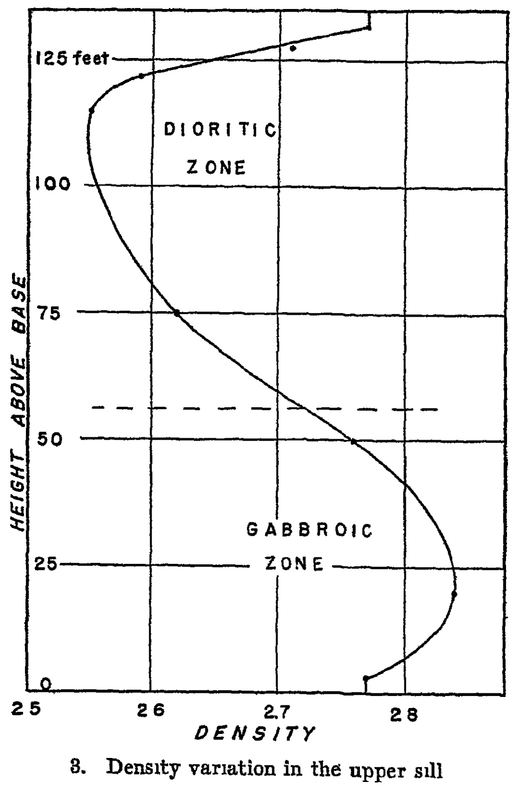
Mineralogically rocks of the dioritic zone are comparatively poor in ferromagnesian minerals and rich in feldspar and quartz. The feldspars show moderate to strong deuteric alteration to saussurite and zeolites. They are zoned with cores of An_{60} and rims of An_{30} to An_{46}. The core and rim are separated by a transition zone having a gradual change in extinction angle.

Thin sections through vugs from the dioritic zone show that these spaces are lined with euhedral quartz followed by stilbite, and rarely chabazite, with calcite in the center. Wisps and rosettes of moderately birefringent chlorite occur in the calcite as though formed by replacement. The quartz has been slightly replaced by stilbite and calcite. Calcite has replaced stilbite and plagioclase to a limited extent. Quartz and apatite are common minerals of this zone but are absent or rare in the lower zone.

A fine-grained porphyritic border one to three feet thick is found at the top of the section. It is identical petrographically with the basal chilled zone. A small sill of similar composition three feet thick is exposed at one place a few feet above the upper sill.

Rock directly in contact with the intrusives was seen at only one place, i.e., above the upper sill. The rock, a fine-grained sandstone, is unaffected except for a one or two cm. zone that has been indurated slightly more than the remainder of the sandstone.

Several small, nearly vertical, lamprophyric dikes cut the upper sill. They range from a few inches to ten feet in thickness. None were found cutting the sediments.



3. Density variation in the upper sill

Table I and Fig. 3 show the systematic variation of petrographic properties and density in a typical vertical section of the upper sill. Some sections of the lower sill are essentially the same.

One of the most significant and marked variations is that of density. The top and bottom zones are the same, 2 76, but the lower, gabbroic part rises to 2.84 and the upper, dioritic part drops to 2.55.

The mineralogical composition which, of course, determines the density of the rocks, shows an equally systematic change from top to bottom. The most important of the mineralogical

TABLE I.

Rosiwal Analyses of Rocks of the Upper Sill

Feet above base		Augite	Hypersthene	Hornblende	Quartz	Micropegmatite	Chlorite	Alterations[3]	Apatite	Iron ore	Plagioclase	% An. Core	% An. Rim	Vugs	Density	Femic/salic min
	Pheno	1	1	0	0	0	0	0	0	0	24	60		0		
133[1]														0	2 76	0 45
	G M.[2]	22	0	0	0	0	5	0	0	2	45	45		0		
127		11	1	0	0	0	4	10	R[4]	2	72	60	46	0	2 71	0.22
122		1	0	3	3	23	3	25	C[4]	3	39	60	30	C	2 59	0 11
115		1	0	1	5	21	6	23	C	3	40	60	30	C	2 55	0.12
75		10	0	0	1	R	3	5	R	1	80	60	38	0	2 62	0.16
50		25	1	0	1	0	5	3	R	3	65	60	45	0	2.76	0.52
20		30	1	0	R	0	5	0	R	1	63	60		0	2.84	0 59
3		20	1	0	0	0	5	0	R	3	71	60		0	2.76	0.41

[1] The base of the sill is not exposed in this section but where seen elsewhere it is similar to the rock described in this column

[2] Groundmass makes up 74% of this rock.

[3] Mostly feldspars altered to zeolites, saussurite, etc.

[4] R-rare; C-common.

variations is the ratio of femic to salic minerals. The dioritic zone is distinctly low in augite, whereas samples of the lower, heavier zone contain up to 30 per cent of this mineral. This variation is reflected in the color of the rocks, there being a complete gradation from the dark gray gabbro to the light-gray diorite.

The plagioclase not only varies in the amount present but also in its composition. The plagioclase of the lower 40 feet and the phenocrysts of the chilled borders are fairly fresh, unzoned labradorite (An_{60}). Higher in the sill the plagioclase is zoned. Excepting the uppermost 10 feet, the albite content is a direct function of its height above the base.

The dioritic zone is marked by the presence of hornblende instead of the augite and hypersthene of the lower zone. Most of the hornblende is primary but some has been formed by the uralization of pyroxenes.

Quartz and zeolites, mainly stilbite, are important minerals of the dioritic zone which are either rare or absent elsewhere in the sills. Chlorite and apatite are common in the upper part of the sills.

The hypautomorphic granular texture of the lower part characterized by the more or less equant development of the minerals, gives way in the upper zone to a texture dominated by the prismatic habit of hornblende and plagioclase. Even greater differences are apparent in thin sections which reveal the abundance of micropegmatite in the upper parts of the sills.

ORIGIN.

Hypotheses as to the origin of intrusive bodies exhibiting systematic variations such as those just described fall into three groups; (1) assimilation of wall rock by the intrusive; (2) separate intrusions of different composition; (3) differentiation in place of a magma that was homogeneous when emplaced.

Reynolds[4] suggests that the Shonkin Sag laccolith, Montana, is the result of assimilation.

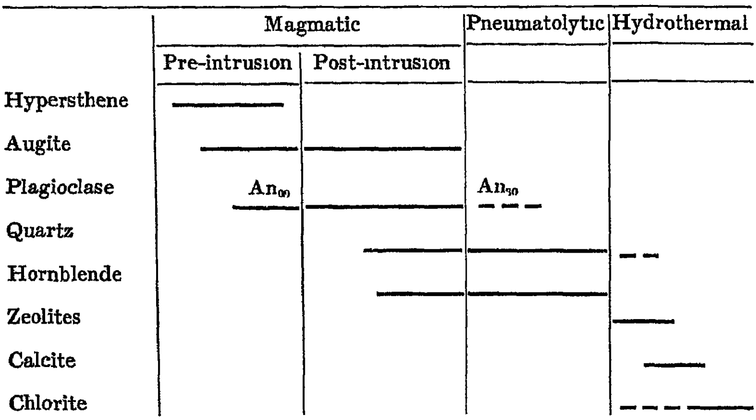
Evidence that assimilation played a part in the formation of the Ashland sills is entirely lacking. Had it been important there should be at least some partly digested inclusions. The contacts between the sills and the sediments would probably not be as sharp and straight and the chilled borders would be absent. Thin sections fail to reveal evidence of assimilation in the form of minerals or textures of non-igneous origin.

Barksdale[5] contends that the Shonkin Sag laccolith was formed by separate intrusions of different composition. The most important criterion for this hypothesis is the nature of the contacts between different phases of the intrusive, sharp contacts being indicative of separate intrusions. The entire absence of any such demarcations in the Ashland sills and the completely continuous and gradational character of changes in the mineral composition, texture, color, and density seem to preclude the applicability of this hypothesis to the case at hand.

Differentiation in place is accomplished by the differential movement of two or more components of a magma. Thus by the sinking of heavy, early formed minerals and/or the floating of light crystals a solid phase may be removed from a liquid phase. Instead of a solid-liquid separation a gaseous phase may be separated or, if liquid immiscibility is accepted, the separation of two or more liquids may occur.

TABLE II.

Sequence of Mineral Formation in Ashland Sills.



Laboratory[6] and field evidence have shown that liquid immiscibility takes place only under certain limited and unusual conditions. There is no indication that such action was responsible for the sills here described.

Abundant evidence in the Ashland sills indicates differentiation in place by crystal settling and possibly by gaseous transfer. These points may be summarized as follows: (1) the gradual, systematic variation of mineral composition with a relative abundance of heavy, early formed minerals in the lower part; (2) the concentration in the upper zone of minerals containing volatile constituents, for example· calcite, zeolites, chlorite, hornblende, and apatite; (4) the occurrence in the upper zone of structural and textural features such as vugs and micropegmatite.

Considering these points it is possible to suggest a sequence of events to account for the origin of the sills. The sequence may have been as follows: (1) The intrusion of a gas-rich homogeneous magma of moderately basic composition. Its composition is probably not accurately recorded by the chilled zone due to the removal of volatile constitutents during crystallization. However, phenocrysts of the borders show that the magma carried about 20 to 25 per cent labradorite crystals and 2 to 5 per cent augite and hypersthene. (2) The sinking of the pyroxenes and to a lesser extent, of labradorite. (3) Lowering of temperature and continued crystallization causing the

remaining liquid to become progressively more rich in alkalies, silica, and volatiles, hence precipitating sodic rims on the plagioclase crystals, hornblende instead of pyroxenes and an increasing amount of quartz. (4) The final crystallization of the upper zone with the formation in locally gas-rich parts of a coarse-grained facies and sporadic vugs. The order of crystallization in the vugs was: quartz, zeolites, calcite, and chlorite. One of the latest events was the hydrothermal alteration of the feldspars and ferromagnesian minerals in the upper zone.

The homogeneous, undifferentiated parts of the sills may represent gas-poor phases of the intrusion. The differentiated parts may have been enriched in volatiles, after emplacement, by the movement of fugitive constituents along certain limited zones in the incompletely crystallized part. A function of the volatiles may have been to increase the fluidity and reduce the density of the residual liquid, thus facilitating the gravitational separation of liquid and crystals.

A sill of similar origin in Bridgland Township, Ontario, was described by R. C. Emmons.[7] It changes progressively from pyroxene gabbro at the base to pegmatitic quartz-hornblende diorite at the top. It is explained as the result of the rising of residual liquor, containing alkalies and silica through the network of early formed crystals with which it reacted to change augite to hornblende, made the feldspar more sodic, and deposited quartz in the last stage of crystallization.

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6. Greig, J W · 1927, Immiscibility in silicate melts, Amer. Jour. Sci 5th Sers, 13, 1-44, 133-154
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SACRAMENTO, CALIFORNIA

LETTER TO THE EDITOR.

AMERICAN CONGRESS ON SURVEYING AND MAPPING.

The American Congress on Surveying and Mapping held its fifth Annual Meeting in Washington, D. C. on June 23, 1945. Commander Frank S. Borden, of the U. S. Coast and Geodetic Survey was elected President, Major Richard T. Evans was named Secretary-Treasurer, and A. L. Shalowitz was named Editor of "Surveying and Mapping," the quarterly journal of the Congress. The meeting included a panel discussion on "Co-operation Among the Technical Organizations," in which representatives from the American Society of Civil Engineers, the American Society of Photogrammetry, the American Geophysical Union, and the American Congress on Surveying and Mapping participated.

The Congress on Surveying and Mapping was organized in 1941 for the purpose of advancing the sciences of surveying and mapping and to contribute to public education in the use of maps and to encourage the promotion of basic mapping programs.

A. L. SHALOWITZ, *Editor,*
"Surveying and Mapping."

ERRATA

"CALCITRO FISCHERI," by Alexander Petrunkevitch (American Journal of Science, vol. 243, 1945, pp. 320-329): Corrections

Page 326, first line in last paragraph, for "in the second pen base" read "in the third pen base."

Page 329, line 10, for "The paratype" read "The slide showing appendages." The paratype of *Calcitro fischeri* belongs to the Natural History Museum of San Diego.

SCIENTIFIC INTELLIGENCE

CHEMISTRY.

Inorganic Chemistry. FRITZ EPHRAIM. American Photo-reprint Edition of the Fourth English Edition; by P. C. L. THORNE and E. R. ROBERTS. Pp. xii, 921, many figures. New York and Scotland, 1943 (Nordeman Publishing Co., $8.75) —This revision of Ephraim's well-known work corrects the material to 1943. As the English authors point out in their preface the improvements are of the nature of substitutions rather than of additions. (Perhaps the principal addition is that of a discussion of artificial radioactivity.) The book is divided into six parts: I. *Elements;* II. *Halogen Compounds;* III. *Oxides of Hydrogen and the Metals;* IV. *The Compounds of Sulfur, Selenium, and Tellurium;* V. *The Nitrogen, Phosphorus, Arsenic Group;* VI. *The Elements of the Fourth Group (and Boron).* The appendices include a collection of diagrams of typical crystal lattices with lists of compounds exhibiting these structures. The first section contains discussions of fundamental material such as atomic structure, the periodic table, and valency. It concludes with chapters on the modifications of and preparation of the elements. An interesting discussion of colloid chemistry is to be found here. Though the authors make the specific statement that a complete discussion of colloids cannot be given, it seems unfortunate to use, as they do on p. 101, such a term as "isoelectric point" with little or no explanation. For a book which is certainly most useful as a reference work such incompleteness is, however, no doubt permissible.

In the later sections of the book, as the titles indicate, the profitable procedure of discussing large classes of compounds is followed. The qualitative character of some of the discussions is illustrated by that for the precipitation of zinc sulfide by hydrogen sulfide. To illustrate the effect of the ionization of H_2S in the precipitation of ZnS Ostwald's data of 1879 are quoted in which the initial concentration of *zinc sulfate* determines the extent of precipitation. While such a procedure is interesting, it does not give the impression of generality which every freshman chemist is supposed to acquire regarding this matter. However, the analytical chemist will find much to interest him in this book. For example, the section on thiosalts contains a broad hint as to the reasons behind the difficulties in precipitating molybdenum sulfide.

None of the section titles hints that the book concludes with a lengthy discussion of intermetallic compounds and hydrides of the metals.

The book manufacture is perhaps as good as can be expected for

1944 Though the paper is poor the printing is clear. The book should continue to be useful to any whose work borders on inorganic chemistry and will certainly supply ample material on which to base advanced courses in the subject. H. C. THOMAS.

Formaldehyde; by J. FREDERIC WALKER. Pp. xi, 393; 31 figs. New York, 1945 (Reinhold Pub. Corp., $5.50).—This book constitutes an excellent addition to this series of works on specialized topics. It contains an abundance of information on the manufacture, properties, reactions and uses of formaldehyde, and workers in such fields will find it an invaluable reference. Those who are concerned with plastics will also find this book of great utility, since by far the biggest use of formaldehyde is in the manufacture of resinous materials.

The first chapter is devoted to historical, statistical, and production aspects of this important industrial chemical. The next six are concerned with physical and thermodynamic properties of the gas, the liquid, its solutions, and the polymers. The next eight chapters present the chemical properties and reactions of formaldehyde, classified according to that with which reaction occurs and including the behavior with inorganic agents, hydroxy compounds and mercaptans, aldehydes and phenols, acids and esters, amines, and hydrocarbons. The next two chapters are concerned with the detection and the determination of formaldehyde. In the last three chapters attention is turned to hexamethylene tetramine and the uses of formaldehyde in chemical manufacture.

The book is well organized, the subject matter suitably classified, and the index adequate. It is regrettable that certain new uses developed during the war could not be included, but certainly the aspects prior to this period are thoroughly reviewed.

HARDING BLISS.

GEOLOGY.

Early Man and Pleistocene Stratigraphy in Southern and Eastern Asia; by HALLAM L. MOVIUS, JR. Peabody Museum, Harvard Univ. Papers, vol. 19, No 3, VI + 113 pp., 47 figs. and 6 tables, 1944.—Movius's book is that rarity in geological literature, a first class compilation of widely scattered literature. The purpose of the book is archaeological, and he has established for the first time the existence of an early Paleolithic industry, the chopper, chopping-tool complex, distinct from the familiar hand ax industry of the classic European sites. To the geologist the successful establishment of the idea of a bipartite division of early industrial development is less important than the accompanying summaries of Pleistocene geological history of various areas in Eastern Asia.

Here in short compass are brought together the pertinent geological results of de Terra's expeditions to Northwest India and Burma, together with the work of his co-workers and predecessors; a critical summary of the years of effort in China largely by members of the Cenozoic Laboratory of the Geological Survey of China; and the results of the important researches of von Koenigswald and other members of the Netherlands Indies Geological Survey in Java.

The Pleistocene history of this farflung area is related in part by reason of similar tectonic history, but largely by the integrated effects of the great fluctuations of climate of the Pleistocene. The stratigraphic succession and the sequences of geomorphic events vary from one of these great regions to another. The sequences of vertebrate faunas afford, however, common time horizons, and, as Movius shows, there is a correlation between the related stone industries.

Those who are familiar with the monograph by de Terra and Patterson on the Yale Northwest India Expedition (Carnegie Inst. Wash. Publ No. 493) or with de Terra and the Movius on Burma (Amer. Phil. Soc. Trans. 1943) will find little that is new in the discussion of these areas. However, these brief, crisp summaries afford a valuable guide to the longer field reports.

The summary of the Pleistocene geology of Java is invaluable. The existing literature is widely scattered and largely preliminary. Movius and de Terra were accompanied in the field by von Koenigswald so that much of his large field experience is here recorded for the first time. Further, the war has made Java inaccessible and much valuable work on its geology may be permanently lost. The Pleistocene of Java began with estuarine and fluviatile beds, containing a vertebrate fauna of Villafranchian aspect There was a gradual emergence of the island from the sea in a general west to east direction. The two formations are thought to cover the time intervals of the First Glacial and First Interglacial stages. In the upper beds an infant skull records the presence of man. The Middle Pleistocene (Second Glacial and Second Interglacial) is represented by the Kaboeh beds. The lower part of these beds contain the Trinil fauna and flora of Second Glacial age. Here belongs *Pithecanthropus erectus* securely tied to the stratigraphy by von Koenigswald's find of four individuals of this race in the basal Kaboeh beds at Sangiran The Upper Pleistocene (Third Glacial, Third Interglacial and Fourth Glacial) are represented by the Notopoero Beds separated from the underlying Pleistocene by a strong unconformity. These beds contain a distinct fauna, two types of human remains, and a stone industry which, however, is better developed in terrace deposits considered to be of equivalent age

The Pleistocene geology of Northern China has been intensely studied and the large literature has been confusing to students. It was recently summarized by de Terra (Institut de Geó-Biologie, No. 6, pp. 1-54, Peiping), but on account of the war this paper is a rarity in American geological libraries. Movius's summary covers the same ground in very clear fashion. He leans heavily on the theory that during glacial epochs the cool dry climate of North China extended into South China and conversely in interglacials warm climate extended northward almost to Manchuria. Wind-blown dust is glacial and limey concretions in the dust are glacial or immediately post-glacial. The effect of the warm interglacial climate is to produce a reddening of soils including the calcareous wind-blown dusts (loess). This "rubification" is a climatic indicator of the first importance.

Both de Terra and Movius, following Teilhard de Chardin assign *Sinanthropus* to the Second Interglacial. The Lower Paleolithic chopper-chopping tool industry extends from the Second Glacial to the end of the Third Glacial. The "upper cave" industry is assigned to the later part of the Fourth Glacial. It will be noted that the events of the Fourth Glacial are indistinctly known. The Malan loess is, as Thorp (Geol. Survey China) has shown, a highly complex deposit. The sequence of geologic events and the presumably parallel cultural development of man remain to be worked out. From the standpoint of the antiquity of man in America, this part of the Pleistocene and its parallel archaeological sequence is most important. If, as appears most probable, man came to the New World from Eastern Asia in the Second Interstadial of the Fourth Glacial (Bryan, 1941, *Science*, **93**, 505-14), the events of this stage in North China are of critical importance. It is, however, important to realize that the latest stone industry of China (upper cave at Choukoutien) is a legitimate descendent of the chopper-chopping tool industry of the Middle Pleistocene of Southeast Asia. If the American stone industries are derived from similar upper Paleolithic industries in Northeast Asia, it is no longer surprising that there is so little resemblance between the tools of the early Americans and the late Paleolithic peoples of Europe.

KIRK BRYAN.

Miscellaneous Scientific Intelligence.

Japan, a Physical, Cultural and Regional Geography; by GLENN THOMAS TREWARTHA. Pp. xv, 607; 281 figs. Madison, Wis., 1945 (The University of Wisconsin Press, $5.00).—It is a real pleasure to be able to review a book such as Trewartha's *Japan*. The author has long been familiar with that country and has studied the litera-

ture upon it very extensively. He has gotten out his book at an especially critical time. The book is conventional in arrangement, but not in content. The first section is on the physical equipment and resources of the country as a whole. It treats of earth materials and surface configuration, climate, natural vegetation, soils, and economic minerals. The second section also treats of the country as a whole, dealing this time with cultural features including population and culture, settlements and houses, agriculture and fishing, manufacturing, and communications and trade. Finally, a third section, comprising almost half the book, treats of the regional subdivisions of Japan beginning in the North and proceeding to the great "inner zone of southwest Japan."

In spite of this highly standardized arrangement, the book contains a great deal of variety and ingenuity. Excellent maps and photographs are used freely and effectively. Statistics occupy a prominent position, and on some pages seem somewhat excessive to the average reader, but not to the careful student. One of the best features of the book from the scholarly standpoint is that so many facts are stated in exact numbers. For the benefit of the less exacting reader there are also many pages of admirable description.

One of the most prominent impressions made by the book is the extraordinary number of people in comparison with the natural resources. The rural people are said to live on the "very cheese rind of existence," and the farms set the standard of living for the whole country. Many Americans who read this book will realize as never before how fully Japan has become urbanized and industrialized, with 50 per cent of its people in cities. They will also realize how difficult it must be for a nation to move toward high standards of living like ours with the help of only a quarter of an acre of cultivable land per person and an equally meager supply of minerals.

In so good a book one hesitates to mention flaws. It seems to the reviewer, however, that the author does not lay sufficient stress upon the inadequacies of the Japanese diet nor upon the advantages of the Japanese climate. It is truly said, for example, that the Japanese have shown remarkable skill in increasing the yield of their crops, but it is not made clear that the high yield of crops is due to far the most favorable climate in all Asia as well as to human ability. The importance of fishing likewise seems to be over-estimated. Twenty per cent of the population are said to be "engaged in, or . . . directly or indirectly supported by fishing," but the next page says that only 1,410,000 persons are engaged in that occupation. The consumption of fish per capita is indeed three or four times as great in Japan as in the United States, but "support" according to Webster means "to furnish with means of maintenance

. . . to supply food, clothing, shelter." Another statement which might be modified is that in 1935 Japan actually exported more food products than she imported. This is true if Korea and Formosa are counted as parts of Japan. Those two regions ship a great amount of rice and sugar for the support of Japan's urban population. They are rigidly excluded from Trewartha's book, however, not even being mentioned in the index. The Japanese, on the contrary, include them in many statistics such as those on which Trewartha's statement is based. Such defects, however, are a minor matter in a book which is so timely, so well written, and, in general, so reliable, and so warmly to be recommended. ELLSWORTH HUNTINGTON.

PUBLICATIONS RECENTLY RECEIVED

The Idea of Nature; by R. G Collingwood New York, 1945 (Oxford University Press, $4 00).

Tennessee Geological Survey. Bulletin 52 Geology and Manganese Deposits of Northeastern Tennessee; by P. B King, H W. Ferguson, et al. Nashville, 1944.

U. S. Geological Survey Bulletins as follows· 935-H Manganese Deposits in Costa Rica; by R. J Roberts Price $.15; 936. Strategic Minerals Investigations, Pt 1, A-1. Short Papers and Preliminary Reports; by T. L. Kesler, W. H Monroe, D Gallagher and others; 936-R Manganese Deposits in the Artillery Mountains Region, Mohave County, Arizona, by S. G Lasky and B. N Webber. Price $1.25; 937. Bibliography of North American Geology, 1929-1939 Pt 1 and Pt 2, by E. M Thom. Price $2 50 each, 942. Geological and Geophysical Survey of Fluorspar Areas in Hardin County, Illinois. Pt 1 Geology of the Cave in Rock District, by L. W. Currier Pt. 2. An Exploratory Study of Faults in the Cave Rock and Rosiclare Districts by the Earth-Resistivity Method; by M K Hubbert. Price $1 25, 1944

Frontiers in Chemistry Vol. 3. Advances in Nuclear Chemistry and Theoretical Organic Chemistry; edited by R. E. Burk and O Grummitt. New York, 1945 (Interscience Pub Inc, $3 50).

Illinois Geological Survey. Report of Investigations—No. 102 The Bonding Action of Clays. Pt. 1—Clays in Green Molding Sands, by R E. Grim and F L. Cuthbert. Urbana, 1945.

U. S Geological Survey: 60 Topographic Maps

Kansas Geological Survey Bulletins as follows: 57 Oil and Gas in Eastern Kansas; by J. M. Jewett and G E. Abernathy 58 Stratigraphy of the Marmaton Group, Pennsylvania, in Kansas; by J. M Jewett. Lawrence, 1945.

Geology for Everyman; by the Late Sir Albert Seward New York, 1944 (The Macmillan Co., $3.25).

American Journal of Science

SEPTEMBER *1945*

ERRATA

"CONJECTURES REGARDING VOLCANIC HEAT," by L. C. Graton (American Journal of Science, Vol. 243-A, 1945, pp. 135-259):

Corrections

p. 137—Line 2 of footnote, "are" should be "is."

p. 146—Line 12, "admitted" should be "emitted."

p. 148—Line 14, "general" should be "generous."

p. 193—Line 24—Before "meters" insert "cubic."

p. 214—1st line following 2nd formula near middle of page, "gas" should be "H_2O."

p. 230—10 lines from bottom, not counting footnote, "is" should be "are."

p. 231—For the sentence beginning on line 4, substitute for clarification: "Indeed, the higher crystallizing range of a melt possessing low content of dissolved volatiles is probably a consequence, at least in part, of the necessity to offset, by higher temperature, a viscosity otherwise so high as to impede formation of the initial nuclei that are the necessary forerunner of crystallization."

p. 251—7th line of footnote, after "and" insert "that."

"THE EVOLUTION OF THE HYDROSPHERE," by Alfred C. Lane, (American Journal of Science, Vol. 243-A, 1945, pp. 393-398):

p. 393—Line 15, "higher" should be "lower."

. . . to supply food, clothing, shelter." Another statement which might be modified is that in 1935 Japan actually exported more food products than she imported This is true if Korea and Formosa are counted as parts of Japan. Those two regions ship a great amount

American Journal of Science
SEPTEMBER 1945

NOMENCLATURE OF TRIASSIC ROCKS IN NORTHEASTERN UTAH.

J. STEWART WILLIAMS.

ABSTRACT Tracing outcrops from southeastern Idaho through the central Wasatch Mountains and eastward along the Uinta Mountains shows that the Higham grit of southeastern Idaho equals the "Ankareh grit" of the central Wasatch Mountains and the Shinarump conglomerate of the Colorado Plateaus area. The name "Wood shale" is very appropriate for those beds above the "Ankareh grit" in the central Wasatch Mountains. It is proposed to restrict the name "Ankareh shale" to those red beds between the Thaynes limestone and the unconformity below the Higham grit. A new name, Red Wash formation, is proposed for the red beds at the eastern end of the Uinta Mountains that are equivalent to the Woodside, Thaynes and Ankareh (restricted) formations at the west end.

INTRODUCTION.

DURING the past field season the writer has had the opportunity to visit most of the outcrops of Triassic rocks in a belt extending from Mansfield's area in southeastern Idaho (Mansfield, 1927) (6)* southward through the Park City area in Utah and eastward along the Uinta Mountains to the Dinosaur National Monument near the Colorado State Line (Figure 1).

This study has included sections in the Montpelier area, where the Timothy sandstone, Higham grit, Deadman limestone and Wood shale are recognized. It has covered those exposures in the vicinity of Park City, where the Woodside shale, Thaynes limestone and Ankareh formation were named by Boutwell. And it has been carried eastward along the south flank of the Uinta Mountains, making possible correlation of the Triassic rocks of the Utah-Idaho-Wyoming area with those of the northern part of the Colorado Plateaus area.

THE "ANKAREH GRIT" (HIGHAM GRIT).

In 1907 when Boutwell divided the Triassic rocks of the

* Numbers in parentheses refer to the literature cited

Park City district, he recognized the Woodside shale, the Thaynes limestone and the Ankareh formation. The last as actually defined by him, included all the rocks exposed in his area above the Thaynes limestone, and thus rocks which that same year were being named "Nugget sandstone" by Veatch in southwestern Wyoming (Wilmarth, 1938, p. 55) (11). Very shortly Boutwell (1912, p. 59) (3) revised his definition to conform to Veatch's nomenclature, and since that time the term Ankareh has meant the rocks between the Thaynes limestone below and the Nugget sandstone above. It was so used in the recent U. S. G. S. Professional Paper on the Cottonwood District (Calkins and Butler, 1943) (4).

This stratigraphic interval is tripartite, being broken approximately midway by a unit of coarse-grained sandstone, or grit, with red beds below and above. This grit has been called the "Ankareh grit" in some unpublished reports and the "Suicide grit" in manuscript by Professor R. E. Marsell of the University of Utah (personal communication). Eastward from the Park City area the grit may be traced through the sections on the upper Weber River, Duchesne River (Farm Creek, a tributary), Lake Fork, Whiterocks River and Brush Creek to the Dinosaur National Monument near the mouth of Split Mountain Canyon. Long before this last named section is reached, the grit may be recognized as the typical Shinarump conglomerate of the Colorado Plateaus province. That is, the grit in the Ankareh formation of Boutwell, is the extension, into the area of the central Wasatch Mountains, of the Shinarump conglomerate (Figure 2).

Traced northward through the sections on the lower Weber River and in Indian Canyon to the Montpelier area, this grit is found to be identical with the Higham grit in Montpelier and Home Canyons.

Lithologically the Higham grit in the Montpelier area is a lavender (vinaceous brown) or gray coarse-grained quartzitic sandstone with some pebble conglomerate. It is about 35 feet thick in Montpelier Canyon and the same in Indian Canyon. At the latter outcrop the writer found fossil wood, a characteristic feature of the Shinarump conglomerate in most areas (Mansfield, 1927, p. 374) (6).

At the mouth of Parley's Canyon east of Salt Lake City where the grit is well exposed along the road cut of the Wasatch Boulevard and in Suicide Rock, it appears very sim-

ilar lithologically to the Higham grit in Montpelier Canyon. On the basis of the writer's observation the name "Higham grit" should be used southward in the Park City area and as far

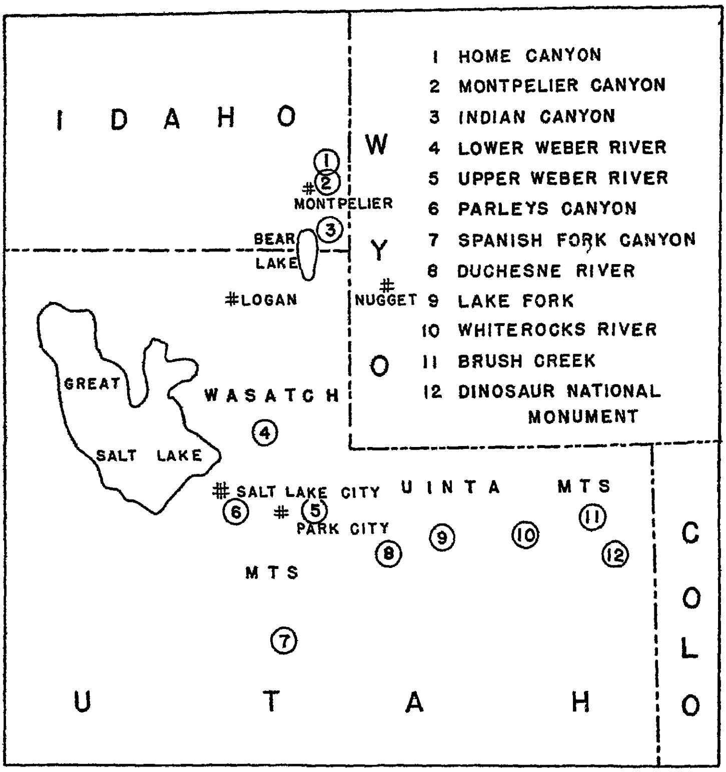

Figure 1. Index map to show the locations of the sections discussed.

Locations of the sections referred to in this paper.

No.	Section	Location	
1.	Home Canyon	T. 12 S., R. 45 E.	Boise Base and Meridian
2.	Montpelier Canyon	T. 12 S., R. 45 E.	Boise Base and Meridian
3.	Indian Canyon	T. 15 S., R. 45 E.	Boise Base and Meridian
4.	Lower Weber River	T. 4 N., R. 3 E.	Salt Lake Base and Meridian
5.	Upper Weber River	T. 1 S., R. 6 E	Salt Lake Base and Meridian
6.	Parleys Canyon	T. 1 S., R. 1 E	Salt Lake Base and Meridian
7.	Spanish Fork Canyon	T. 9 S., R. 4 E.	Salt Lake Base and Meridian
8.	Duchesne River	T. 1 N., R 8 W.	Uinta Base and Meridian
9.	Lake Fork	T. 2 N., R. 5 W.	Uinta Base and Meridian
10.	Whiterocks River	T 2 N., R 1 E.	Uinta Base and Meridian
11.	Brush Creek	T. 2 S., R. 22 E.	Uinta Base and Meridian
12	Dinosaur National Monument	T 4 S., R. 23 E	Salt Lake Base and Meridian

east as the upper Weber River section. East of this the name Shinarump conglomerate is best.

The undesirability of continuing the use of the term "Ankareh formation" in its present sense is obvious from the above discussion.

"UPPER ANKAREH SHALE" OR WOOD SHALE.

The rocks between the Higham grit and Nugget sandstone in the Park City area consist of lavender clay shales followed by brick-red thin-bedded sandstones and sandy shales. These two lithologic types divide the stratigraphic interval about equally. At the top the shales intergrade with the base of the Nugget sandstone. The same lithologic types and stratigraphic succession may be followed northward through lower Weber Canyon into the Montpelier area, where they constitute the Wood shale. That is, the upper part of the "Ankareh formation" is the Wood shale, and since the term Ankareh in its present meaning must be abandoned, it is desirable to extend the use of the term Wood shale to the Park City area.

In the section on the upper Weber River the "upper Ankareh shale" still has the appearance of the Wood shale, but east of this point lavender and brown-weathering clay shales appear to be the typical constituents of the interval, and they are better called the Chinle formation.

"LOWER ANKAREH SHALE" OR ANKAREH SHALE (RESTRICTED).

The "Ankareh grit" and the rocks above it to the base of the Nugget sandstone have been shown to be respectively the Higham grit and the Wood shale. The rocks below the grit and above the Thaynes limestone constitute a very important stratigraphic unit which thickens from a few hundred feet in the Montpelier area, southward and eastward. In the Montpelier area these red beds are part of the Timothy sandstone. In Indian Canyon on the east side of Bear Lake they are about 100 feet thick. In lower Weber Canyon they have increased to approximately 700 feet and in the Park City area they are about 900 feet of brick-red shale and thin-bedded sandstones, the sandstones becoming thicker bedded toward the top of the unit. Southward in Spanish Fork Canyon the unit is still thicker, reaching 1600 feet, and the sandstones at the top are massive. To these beds it is proposed to restrict the term "Ankareh shale."

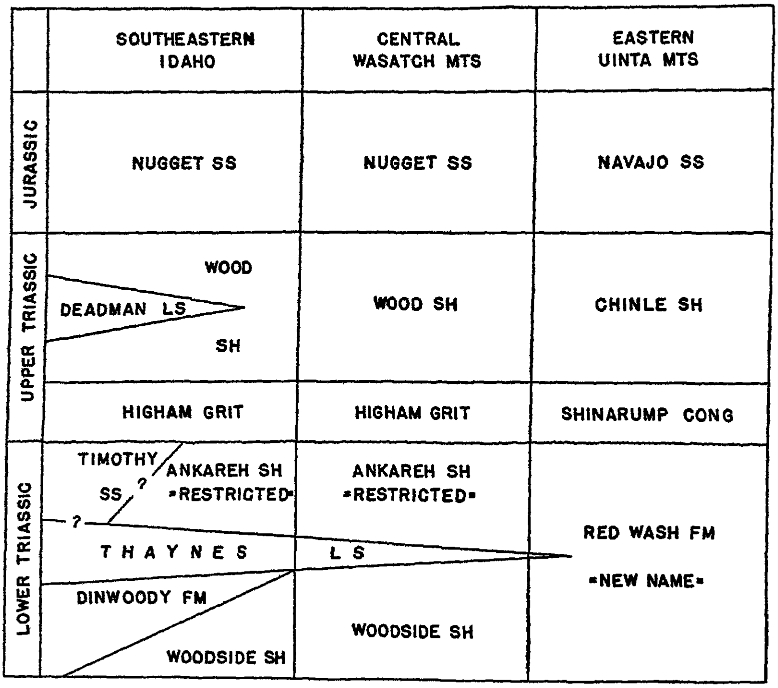

Figure 2. Correlation diagram showing the relationship of Triassic formations in southeastern Idaho to those at the eastern end of the Uinta Mountains, and the suggested nomenclature for Triassic rocks in the central Wasatch Mountains.

RED WASH FORMATION.

As the Woodside, Thaynes and Ankareh (restricted) formations are traced eastward along the south flank of the Uinta Mountains each becomes thinner, and in the vicinity of Whiterocks Canyon the Thaynes limestone tongue disappears completely. It is clear from these relationships that the red beds east of that point are in part equivalent to the Ankareh (restricted) sandstone and shale, and in part to the Woodside shale. Neither term alone can appropriately be applied to them, however.

These beds are sometimes designated the Moenkopi formation, but this name is not completely satisfactory because all of the Moenkopi, at least in the Zion Canyon area, is younger than the Woodside shale, the *Meekoceras* zone lying at the base of the former in the Zion Canyon area (Newell and Kummel, 1942, p. 938), (7) and above the latter (in the base of

the Thaynes limestone) in southeastern Idaho (Kummel, 1943, p. 319) (5).

Since none of the terms Woodside, Ankareh or Moenkopi can appropriately be applied to these beds, a new name seems in order. For the name the writer suggests Red Wash formation, from the exposure in the canyon of this name north of the dinosaur quarry in Dinosaur National Monument. The type section was measured north and west of this locality on Brush Creek along a traverse beginning near the mouth of Bush Creek gorge in sec. 3, T. 2 S., R. 22 E., Uinta Base and Meridian, and running southward to the base of the Shinarump conglomerate.

Following is the section:

Shinarump conglomerate Unconformity	Thickness Feet
Red sandstone, thin to thick bedded	100
Earthy thin-bedded sandstone or sandy shale with some thin beds of gypsum	370
Red shales	260
Alternating units of red and gray shale	100
Gray sandy shales with some gray laminated sandstone weathering in plates	250
Total	1080

Unconformity.

Park City Formation.

RED BED TONGUES IN THE PARK CITY FORMATION.

In 1939 the writer (10, p. 91) named a red bed unit in the Park City formation of this area the Mackentire tongue of the Phosphoria (Park City) formation. He was criticized by H. D. Thomas (1939, p. 1249) (8) who suggested that the red beds unit was a tongue of the overlying red beds formation, which was then being called the Woodside, and hence that it should have been called the Mackentire tongue of the Woodside shale. Since that time a great deal of information has accumulated to indicate that a major unconformity overlies the Park City formation, and hence that the red beds tongue in question is much older than any part of the Red Wash formation. If this is so, it is not desirable to call it a tongue of the Red Wash formation. Rather it is a tongue of the unnamed red beds equivalent to the Park City farther east, which are perhaps the "tawny beds" of Brill (1944) (1) and other writers.

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TRIASSIC FAUNAS IN THE CANADIAN ROCKIES.

P. S. WARREN.

ABSTRACT. The Triassic strata of the Canadian Rockies and Foothills have been described under two formational names,—the Spray River formation which includes the exposures of Triassic rocks in the southern Canadian Rockies, and the Schooler Creek formation which includes the exposures on Peace river and vicinity. The writer proposes dividing the Spray River formation into two members, largely on a lithological basis,—the Sulphur Mountain member below and the Whitehorse member above. The Schooler Creek formation has been divided by McLearn into two members, a lower or Grey member and an upper or Pardonet member. It is shown here that the Whitehorse member of the Spray River probably correlates with the lower part of the Grey member of the Schooler Creek

The faunas so far obtained from these formations indicate that a nearly complete sequence of Triassic rocks occur in the Canadian Rockies. The Sulphur Mountain member contains at least two Lower Triassic faunas, the Whitehorse member is definitely Middle Triassic, the Grey member of the Schooler Creek contains both Middle and Upper Triassic horizons and the Pardonet member holds several faunas of Upper Triassic age.

INTRODUCTION.

TRIASSIC formations have been known and studied in the Canadian Rockies for many years. Progress has been slow in gaining a detailed knowledge of the formations and their faunas, firstly, on account of the scarcity of well-preserved fossils in some of the sections studied and secondly, because many of the fossils which were collected represented new species and often new genera, and expert knowledge of Triassic fossils was required to treat the different faunas in a thorough and competent manner. The difficulties of attempting identifications of indifferently preserved specimens from European and Asiatic literature which is quite voluminous and often difficult of access, seemed hardly justifiable. This statement does not apply to the works of F. H. McLearn who for years has been studying the Upper Triassic and some of the Middle Triassic faunas on Peace river and has brought this study to a high degree of fruition. Little progress has been made on the other Triassic faunas in the Rockies, until lately when better preserved collections have unravelled some of the difficulties. The writer believes that a report of progress may be interesting at the present time. No attempt, however, will be made to enter

into the problems in detail or describe any of the species that have been collected.

The writer wishes to thank Mr. C. R. Stelck for his help in providing some critical stratigraphical details.

STRATIGRAPHY OF THE TRIASSIC FORMATIONS.

Two formations of Triassic age in the Canadian Rockies have been delimited and described. They are (1)* the Spray River formation,(3) which has been identified by outcrops in many localities from an area just north of the 49th parallel of latitude to and north of Athabaska river at about the 54th parallel, and(2) the Schooler River formation,(4) which is well exposed on Peace river and is known to extend northward to the Liard river and undoubtedly extends much farther. The southern extension of this formation has always been a matter of doubt. The relationships of these two formations will be discussed in this paper.

DESCRIPTION OF THE SPRAY RIVER FORMATION.

The Spray River formation, originally named the Upper Banff shales by R. G. McConnell, consists, in the lower part, of a series of dark grey, laminated, calcareous, and sandy shales with thin beds of dark grey, fine grained, argillaceous dolomites and limestones. Above these occur a series of light grey, calcareous and sandy beds which vary considerably in different localities. In places these upper beds are soft limestone, in other places they are largely dolomitic with an admixture of sand, and in some places they are reported as calcareous sandstones.

A good section of the Spray River formation has been measured by H. W. Shimer at the west end of Lake Minnewanka, near Banff, Alberta.(7) Shimer gives a thickness of 576 feet of dark grey, laminated beds at the bottom of the section and 922 feet of the light grey, sandy beds above Another section measured by the writer(9) at the south end of Sulphur mountain, 10 miles south of Banff, showed a thickness of 1,243 feet for the lower dark grey laminated beds and 610 feet for the upper light grey limestone intermixed with darker shales. The beds shown in this section above the light grey zone are probably a duplication of the lower laminated beds.

* Figures in parentheses indicate the References at the end of the paper.

Farther north, on the McLeod river, a tributary of the Athabaska, near Cadomin, Alberta, the Spray River formation is well exposed. The section is thinner and the writer has no exact measurements at his disposal. The two members of the formation are distinctly shown, the lower dark grey laminated beds below, overlain by light grey, almost white, chalky limestone. The white limestone bed has a wide distribution through this area where it makes an admirable horizon marker and has been called the Whitehorse member by field geologists from exposures on Whitehorse river, a tributary of the MacLeod.

North of Cadomin, on Athabaska river in Jasper Park, the Spray River formation is present in several sections. No complete section is exposed and measurements have not been obtained. Various local exposures demonstrate, however, that both members are present in this area. The upper light grey member contains a considerable amount of sand and may be termed a calcareous sandstone. In one exposed section of the light grey member, at the foot of Mt. Cinquefoil, the uppermost beds are overlain by gypsum and other evaporites. The gypsum bed is immediately overlain by the basal bed of the Jurassic.

The gypsum bed in the upper part of the Spray River formation continues northward through the mountains and has been studied by J. A. Allan(1) in townships 51 and 52, range 5, west of the 6th meridian. It is also shown in the log of the Guardian well in township 80, range 12, west of the 6th meridian.(2)

The name Spray River formation has not been applied to Triassic beds north of Athabaska river, in published reports.

DIVISION OF THE SPRAY RIVER FORMATION INTO MEMBERS.

The Spray River formation may be divided quite naturally into two members: the lower member consisting of dark grey to black, laminated shales and dark grey, fine-grained limestones or dolomites which we may designate the *Sulphur Mountain* member, from the fine section of these beds at the foot of Sulphur Mountain in the Spray gorge, 10 miles south of Banff; and secondly, the upper member of light grey to whitish limestones, dolomites, sandy dolomites or sandstones with sometimes an intermixture of darker shales and, to the north, evaporites such as gypsum. The name already in use by field geologists for this succession of beds is the *Whitehorse* member of

the Spray River and that name will here be recommended for official use.

The division into members is based directly on lithological characteristics but palaeontological evidence may also be useful. The faunas so far obtained from the Sulphur Mountain member may all be ascribed to the Lower Triassic, whereas the collections so far obtained from the Whitehorse member are Middle Triassic in age. The boundaries between the Lower and Middle Triassic may not coincide with the boundary between the two members.

BOUNDARIES OF THE SPRAY RIVER FORMATION.

Where a normal section is present, the Spray River formation lies apparently conformably on the Rocky Mountain Quartzite of Pennsylvanian and Permian? age. Although there is undoubtedly a time break represented at the base of the Spray River, there is no discrepancy in the dip of the two contiguous formations. In the northern extension of the Spray River formation, in the neighborhood of Cadomin and the eastern ranges on Athabaska river, the Rocky Mountain Quartzite has a more limited lateral extent than the Spray River beds, and the latter formation is found lying directly on the Mississippian Rundle limestone.

In all normal sections examined the Spray River is overlain by the Fernie (Jurassic) formation.

DESCRIPTION OF THE SCHOOLER CREEK FORMATION.

The name Schooler Creek formation was given by Dr. F. H. McLearn(4) for a succession of Triassic rocks exposed in the valley of Peace river, west of Hudson Hope. The formation is exposed in a series of folds and fault blocks which form the foothills of the Rocky Mountains. It consists of a series of fine sandstone and siltstone, usually calcareous, with beds of argillaceous and arenaceous limestone and dark carbonaceous beds.

McLearn(5) has divided the formation into two rather indefinite members: an upper series of dark carbonaceous strata consisting of argillaceous limestone and calcareous siltstone with a thickness of about 300 feet which he designates the Pardonet member and a lower series containing light grey more arenaceous beds which he terms the lower or Grey member,

which is over 2,000 feet in thickness. The Pardonet member contains an Upper Triassic fauna including the *Halobia* zone and the *Monotis subcircularis* zone. The lower or Grey member

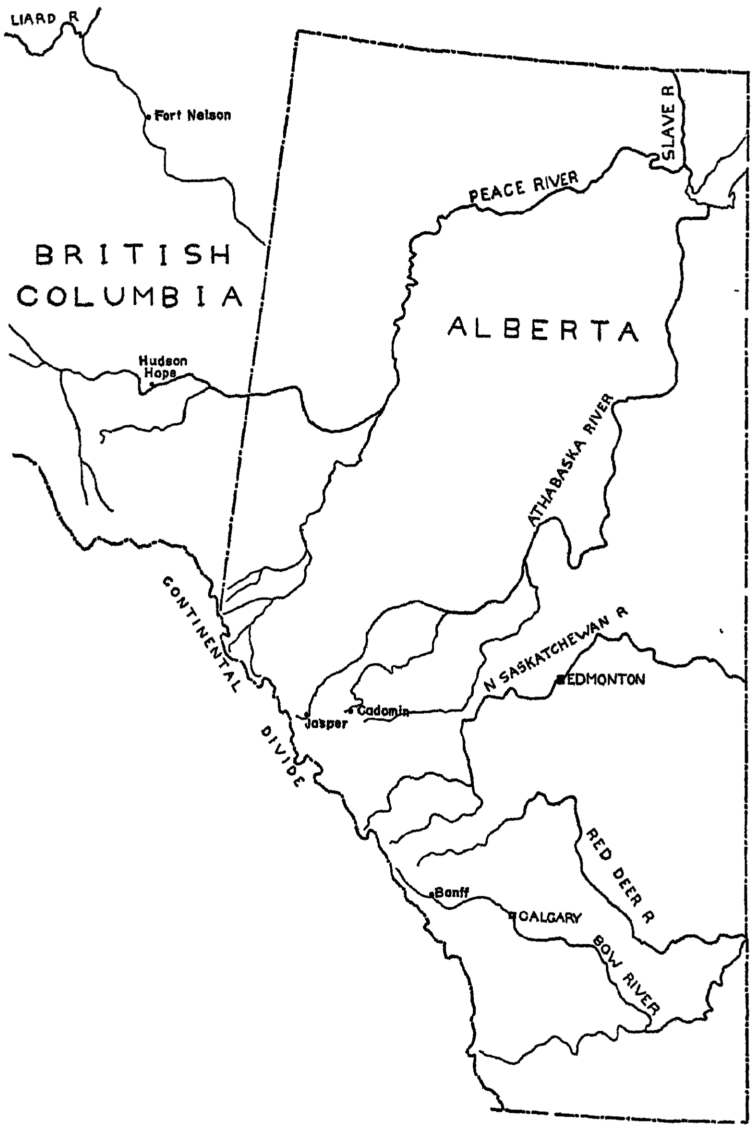

Fig. legend. Map of the Province of Alberta and part of the Province of British Columbia showing the location of places mentioned in this article.

contains several zones of which the lowest or *Nathorstites* zone is the most prolific and best known. McLearn is inclined to place the *Nathorstites* zone in the Middle Triassic and the author is in agreement with this finding.

From petrological and palaeontological evidence, McLearn's Grey member may be correlated, in part at least, with the Whitehorse member of the Spray River formation. The additional thickness of this zone in its northern extension may be accounted for by additional beds at the top of the member. The top of the Whitehorse member of the Spray River is an erosional surface overlain by Jurassic beds, whereas on Peace river the Grey member is overlain by Upper Triassic beds with no erosional interval. The thickening of the Whitehorse member to the north is demonstrated by the position of the gypsum bed. On Athabaska river the gypsum bed is immediately overlain by basal Fernie formation. On Mowitch creek to the north of the Athabaska(1) the gypsum is overlain by some 480 feet of light grey limestone of the Whitehorse member which in turn is overlain by the Fernie. The same conditions are present in the Guardian well in section 7, township 80, range 12, west of the 6th meridian. Near Peace river(2) the gypsum horizon is overlain by about 350 feet of light colored limy beds which probably represent the Whitehorse or Grey member, and they are immediately overlain by the Jurassic.

The Pardonet member is present only in the western fault blocks on Peace river and does not extend far to the south. It has never been reported south of Pine river.

The Sulphur Mountain member also appears to be present on Peace river as in some sections the Grey member is underlain by dark grey laminated shales and limestones, so typical of the Sulphur Mountain member. The lower part of this Triassic section on Peace river appears to be very little known.

FOSSIL HORIZONS IN THE TRIASSIC FORMATION.

Fossil horizons in the Schooler Creek formation have been well studied and worked out by McLearn and published in a long series of papers in the Transactions of the Royal Society of Canada and in the Canadian Field Naturalist. A good résumé of the different faunas is contained in McLearn's paper, "Notes on the Geography and Geology of the Peace River Foothills," published in the Transactions, Royal Society of

Canada, Third Series, Section IV, Volume 34, 1940. The Schooler Creek formation is very fossiliferous in certain sections and lends itself readily for detailed study. The Spray River formation, on the other hand, is usually unfossiliferous and the sections are poorly exposed. The formation usually underlies the valley floors and our knowledge of the formation must often be obtained through erratic exposures. Fossils usually occur in thin beds from two to six inches thick. Such beds are rare and the fossils often poorly preserved. The barren nature of the formation and the lack of good lithological horizons for the correlation of sporadic outcrops mitigates against any thorough knowledge of the formation being obtained. Some interesting details relative to the faunas contained in the formation have come to hand and although the evidence is meagre and based largely on imperfect specimens, it is sufficient to indicate in a general way the age of the containing beds.

The lowest fossil horizon so far found in the Sulphur Mountain member of the Spray River formation is contained in a bed at, or near, the base of the member. This bed is replete with fairly well preserved specimens of *Claraia stachei* (Bittner), a well known Lower Triassic pelecypod. Closely associated with this *Claraia* bed, though not, so far, found in the same sections, occurs a black magnesium limestone bed containing many flattened ammonites. The preservation of the ammonites prohibits definite identifications. However, careful study of the specimens, and taking into consideration their association with *Claraia stachei*, leads to the conclusion that the following genera are represented: *Ophiceras*, *Proptychites* and *Otoceras*. The forms referred to the genus *Ophiceras* are the most abundant and seem to agree in size, shape of the conch and width of the umbilicus with *O. demissum* (Oppel). No suture has been obtained from any of the specimens. The forms listed as *Otoceras* are next in abundance. The keel is well known in all the specimens, the sharp umbilical rim is well expressed and the spiral ridges were observed in one specimen. No suture has been observed. The specimens are comparable in size and other external features with *O. fissistellatum* Diener. The form listed as *Proptychites* is represented by a fragment of the septate portion of a whorl. The size of the shell, and the septa especially, agree in minutest detail with Spath's species *P. rosenkrantzi* from Greenland.

The fauna listed above is Lower Triassic in age and is world wide in distribution. It represented the lowest faunas in the Triassic and has been reported in the western hemisphere from Nevada(6) and Greenland.(8) Muller and Ferguson, who recently described a similar fauna from the lower beds of the Candelaria formation in Nevada, give a good summary of the distribution of the fauna in the Tyrol, in Greenland, and in India.

Above the ammonite bed of the Sulphur Mountain member, fossils are very scarce. One bed has yielded a fine selection of pelecypods of the *Monotis* type, but the genus has not been definitely determined and it seems to have little stratigraphic value at the present time. At some 600 feet above the base of the member, a horizon yielding *Flemingites?* is important. The genus has been determined by external features only. The species is large, from six to eight inches in diameter and the spiral ornamentation is well preserved. There seems little doubt as to the generic determination. The horizon appears to be wide spread as it has been obtained from three widely spaced localities. At much the same horizon in one locality, several specimens of *Claraia griesbachi* Bittner have been identified.

The *Flemingites* fauna has a wide distribution. It is a well known North American fauna and the genus serves to link this horizon of the Sulphur Mountain member with the *Meekoceras* beds of Idaho and the *Flemingites* beds of India.

No fossil horizons have been detected in the Sulphur Mountain member above the *Flemingites* horizon. The section of rock above this horizon must be quite thin as the *Flemingites* horizon is about 600 feet from the base and most sections of the Sulphur Mountain member do not measure much more than 600 feet and some are less. The sections nearest the foothills are the thinnest, probably as a result of an overlap in that direction, cutting out the lowest beds of the member.

FOSSIL HORIZONS IN THE WHITEHORSE MEMBER.

The fauna of the Whitehorse member of the Spray River formation has been collected from several localities but collections are yet too meagre to justify the delineation of definite horizons. The member is usually not more than 300 feet thick and the species collected may have a stratigraphical range throughout the whole member. The fauna collected from the

Whitehorse member which has been identified and of stratigraphic value, is listed below:

Lingula selwyni Whiteaves
Daonella dubia Gabb
Hornesia cf. *socialis* (Schlotheim)
Trigonodus? productus Whiteaves
Arcestes? sp. not determined
Ceratities (Gymnotoceras) blakei Gabb
Nathorstites cf. *mcconnelli* Whiteaves

Most of the fauna listed above was obtained from the base of the Whitehorse member, the exceptions being *Lingula selwyni* and *Trigonodus? productus* which were obtained from the upper beds of the member. *Lingula selwyni* was described but not figured by Whiteaves.(11) This *Lingula* is usually large, being about 25 mm. in length and 15 mm. in width. The sides are nearly parallel though gently convex and converging slowly toward the beak; the front of the shell is truncate or broadly rounded. It has been obtained from several localities in the Whitehorse member. It occurs in the Grey member of the Schooler Creek formation along with the *Nathorstites* fauna. *Trigonodus? productus* has quite a wide areal distribution, having been described from the Triassic rocks on Liard river by Whiteaves.(12) The genus has been reported from several localities in the *Nathorstites* fauna.

The remainder of the fauna is typical of the Middle Triassic. *Ceratites (Gymnotoceras) blakei* occurs in the *Ceratites trinodonus* sub-zone of the *Daonella dubia* zone in the West Humboldt range in Nevada. It is the most prolific species in our collections. The sub-genus has been reported by Williams(10) some 90 miles west of Fort Nelson on the Alaska Highway, together with *Daonella* and *Tridonodus.* It has not been reported so far, from the sections on Peace river. The presence of *Hörnesia* cf. *socialis* tends to link this fauna with that of the Muschelkalk in Germany. Muller(6) reports *Hornesia* aff. *H. socialis* from the Excelsior formation in the Gillis range, Nevada. It was not accompanied by ammonites. The presence of the *Hornesia* in this fauna tends to place the fauna low in the Middle Triassic.

The fauna so far collected and identified from the Whitehorse member of the Spray River formation, is definitely Middle Triassic in age. In comparison with the Triassic section in

Germany, the fossil evidence would tend to correlate the member with the Lower and Middle Muschelkalk. Definite correlation is impossible at the present time.

FOSSIL HORIZONS IN THE LOWER OR GREY MEMBER OF THE SCHOOLER CREEK FORMATION.

The fossil horizons of the Schooler Creek formation have been well worked out by McLearn and the fossils described. There are two well defined faunal zones in the lower or Grey member. The lowest faunal zone occurring in the lower part of the member is named after the most prolific ammonite, *Nathorstites*. Other ammonites commonly found at this horizon include *Protrachyceras* and *Isculites*. Brachiopods include *Lingula selwyni*, *Spiriferina* and *Coenothyris*. Pelecypods are plentiful including *Monotis montini* McLearn, *Hornesia*? and *Daonella*. McLearn is inclined to place this fauna in the Ladinian or late Meso-Triassic and the writer agrees with this designation. It cannot be very far separated from the *Ceratites* (*Gymnotoceras*) *blakei* fauna found at the base of the Whitehorse member of the Spray River as some species are common to the two faunas.

This fauna cannot be correlated with known faunas from Nevada or California, as Ladinian faunas appear to be lacking in that area. It may be the lack of Ladinian faunas in the California and Nevada area which seems to give a "boreal" aspect to the *Nathorstites* fauna.

The second fauna of the Grey member of the Schooler Creek formation occurs near the top of the grey beds in the *Lima*? *poyana* fauna. It represents an assemblage of pelecypods, mostly new species, which McLearn would prefer to correlate with some part of the European Karnian. The fauna does not seem to occur in the California or Nevada area.

FOSSIL HORIZONS IN THE PARDONET MEMBER OF THE SCHOOLER CREEK FORMATION.

The faunas of the Pardonet member are all Upper Triassic in age. The lower part of the member contains a *Halobia* fauna and a *Monotis subcircularis* fauna occurs near the top of the member. According to McLearn, the *Halobia* zone con-

tains three distinct ammonite faunas which, in ascending order are: the *Stikinoceras* fauna including species *Juvavites*, *Tropites* and *Thisbites*; the *Drepanites* fauna, containing species of *Juvavites* and *Cyrtopleurites*; the *Distichites* fauna containing many genera of Upper Triassic age, including species of *Distichites*, *Isculites*, *Himavatites*, *Helictites* and *Pinacoceras*. *The Stikinoceras* fauna is placed in the Upper Karnian and the *Drepanites* and *Distichites* fauna are considered Lower Norian in age. These faunas show Mediterranean and Himalayan affinities.

The upper part of the Pardonet member contains the well known *Monotis subcircularis* of Upper Norian age. Closely associated with it is the ammonite *Diphyllites* fauna which also includes *Placites*. It is the uppermost fauna so far found in the Pardonet member. The *Rhaetic* faunas are apparently not represented in the section.

CONCLUSIONS.

A fairly complete sequence of Triassic rocks is present in the Canadian Rockies, represented by the Spray River formation in the south and the Schooler Creek formation on Peace river. The Spray River formation composed of two members, the Sulphur Mountain and the Whitehorse, contains Lower and Middle Triassic faunas respectively. The Schooler Creek formation on Peace river, composed of two members, the lower or Grey member and the Pardonet member, contains Middle and Upper Triassic faunas. It is believed that the lower part of the Grey member of the Schooler Creek formation may be correlated with the Whitehorse member of the Spray River formation. It is also believed that the dark laminated shales and limestones at the base of the Grey member probably represent the Sulphur Mountain member of the Spray River formation.

The boundary between the Triassic formations and the overlying Jurassic Fernie shale is an erosional disconformity. The erosional interval is greatest in the south where the Fernie overlies Middle Triassic beds, whereas on Peace river a thicker section of Middle Triassic beds as well as Upper Triasic beds are present below the Fernie. A greater erosional interval is also shown in the eastern sections of both the Spray River and Schooler Creek formations. It is only in the most westerly section on Peace river that the highest Triassic faunas are

obtained and the thinnest sections of the Spray River are found in the eastern range.

The various faunas of the Lower and Middle Triassic are not fully represented. No Lower Triassic faunas above the *Flemingites* zone have been obtained and the lower faunas of the Middle Triassic are doubtfully present. It is quite possible that there is an erosional unconformity between the Sulphur Mountain and Whitehorse members of the Spray River formation, which is responsible for the missing faunas.

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TWENTY-FIVE YEARS OF STUDY OF THE QUATERNARY IN THE U. S. S. R.

V. GROMOV.

FOREWORD BY THE TRANSLATOR.

The review by Professor Gromov is an account of some of the most important accomplishments of Russian scientists in the field of Quaternary geology and paleontology in the last quarter of a century. It serves as a good introduction to the subject, and includes a valuable stratigraphic summary, but is not supplemented by a bibliography. Fortunately, the extensive bibliography on extra-American geological literature which is being published annually by the Geological Society of America, and the annotated bibliography periodically published by the Society of Economic Geologists, include many of the works mentioned by Gromov.

Because the subject reviewed by Gromov is so vast, and probably because he wrote under a great handicap created by the war, which destroyed or greatly reduced and inconvenienced most scientific activities in the U.S.S.R. (hence lack of bibliography)—his review does not include some individual Russian contributions on the subject, which have been received here and which are important. Such is the paper by N. B. Vassoevitch (1934) on late orogenic phases in the Caucasus, where he discusses the whole problem of the Pliocene-Pleistocene differentiation; his paper is accompanied by a good bibliography of the Russian and Western European literature on the subject. A very able review and discussion on the latest epeirogenic movements in the region adjacent to the northern part of the Caspian Sea was published by N. I. Nikolaev and B. V. Poliakov (1937) and a short but well written and illustrated discussion on the origin of the successive Quaternary marine and river terraces by A. I. Moskvitin (1937), who correlates the terraces of the Mediterranean worked out by Deperet, the terraces of the Black Sea worked out by Lichkov, and the terraces along the Black Sea studied by himself. A most ambitious and fascinating account of the late Tertiary, Quaternary and recent history of the Caspian Sea and its historically recorded repeated connections and disconnections with the water basins

to the west, east and north, was published in the form of a small book by Professor S. A. Kovalevskii, (1933, very completely reviewed by B. B Zavoico in the Bull. Am. Ass. Petr. Geol., vol. 19, 1935, p. 120). In an excellent paper (in Polish and English) devoted to the history of the recent floras around the Black Sea and the Eastern Mediterranean, Mrs. Hanna Chechotova (the widow of Professor Chechot of the Mining Institute of Leningrad) discussed the recent changes in the configuration of their shores and the history of the Crimean peninsula and the Azov Sea.

These are only a few outstanding papers (available at the library of the Nebraska Geological Survey), all concerning the Quaternary geology of the southern part of European U.S.S.R. and adjacent territory, which I selected from the scientific treasury recently published in Russian, Ukrainian, Polish, and other slavic languages. Most of it, if not all, should be made available to those American scientists who specialize in the Quaternary and wish to contribute to the correlation of American and European deposits of this age. The important problems of international scope, such as the number of Pleistocene glaciations and their possible intercontinental correlations, the boundary between Pliocene and Pleistocene, the migration of late Cenozoic faunas and floras, and others, cannot possibly be approached except by close coöperation between Russian and other European and Asiatic scientists, and their American colleagues. Bringing the Russian literature on this and other scientific subjects to the attention of the American scientists, and assistance in making it available to them, is one of the most important functions of the Science Committee of the National Council of American-Soviet Friendship, which it hopes to develop.

M. K. Elias.

ABSTRACT. In the historical sketch of the study of Quaternary the importance of stratigraphic base for paleontologic, mineralogic and other special aspects of the study is stressed Special chapters are devoted to progress in geological mapping, development of mineral resources, study of fossil man, vertebrate and invertebrate animals and plants, and in tectonics. In conclusion the stratigraphy of the Quaternary is given, with a description for each major subdivision of its physiographic expression, lithology, fossil soils, and characteristic faunas and floras. The following subdivisions are recognized, from older to younger: $Ng\frac{1}{2}L$ Pliocene and $Ng\frac{2}{2}M$ Upper Pliocene (the two are reviewed because some Russian authorities place them in basal Pleistocene). Q_IM Lower Pleistocene

(Mindel), Q^1_{II} Middle Pleistocene (Mindel-Riss), Q^2_{III} Middle Pleistocene (Riss Glaciation), Q^1_{III}RW Upper Pleistocene (Riss-Wurm), and Q^2_{III} Upper Pleistocene (Wurm) The author adheres to the idea of a single major glaciation in Quaternary time, basing this contention chiefly on the stratigraphic and paleogeographic distribution of mammals and terrestrial floras.

THE Quaternary occupies vast areas in the territory of the Soviet Union and has considerable scientific and practical importance. Geologists, geomorphologists, zoologists, paleontologists, botanists, archeologists, anthropologists, and economists—all have an interest in it, and now, in war time it assumes a new importance from a military point of view.

The studies of the Quaternary faunas, or floras, or fossil soils, or lithology, though instructive, do not reveal a true picture of Quaternary history, unless they are coördinated and interwoven into the fundamental study of the complex stratigraphy of this geological period. Unfortunately an underestimation, or even complete disregard of the stratigraphic factors, has done much harm in the studies of the Quaternary.

Clearly, without an understanding of the geological history of a region, no intelligent plan for search of useful minerals or for their rational exploitation are possible, either in war or in peace.

In pre-Revolutionary days it was a custom not to show any Quaternary deposits on the geological maps at all, as their economic importance was not recognized. Later, through the labor of the Soviet explorers, such as A. Pavlov, J. Edelshtein, P. Tutkovskii, N. Bogoliubov, N. Kryshtofovich, V. Obruchev, S. Yakovlev, Nabokikh, G. Mirchink, P. Pravoslavlev, and others (in Geology), J. Cherskii, M. Pavlova, N. Andrusov (in Paleontology), F. Volkov, V. Gorodtsov, J. Savenkov and others (in Archeology), some substantial knowledge of the Quaternary and its history has been accumulated, and even attempts were made at a few syntheses. These explorers discovered about ten paleolithic stations and several localities of interglacial floras. They described a considerable amount of valuable paleontological material, and published also a few geological reports, all pertaining chiefly to the European part of the U.S.S.R.

In the course of the first two "Five-year Plans" the accumulation of new facts from the vast territory of the U S.S.R. continued, and some geological syntheses were attempted for a

few selected large areas of the country. By the end of this ten-year period the works on the Quaternary geology, fauna, flora, and fossil man became so numerous, that a need arose for a special authoritative agency to coördinate the work of various specialists. Such an agency was needed also for the direction of their efforts toward the solution of some purely economic problems, and also for the purpose of working out the best methods of approach in various specific problems. In 1927 such an agency was created in the form of the Committee for the Study of the Quaternary at the Academy of Sciences of the U.S.S.R. This Committee, already in the first year of its existence, united more than a hundred representatives of various sciences. Prior to its organization the works of various scientists on the Quaternary were characteristically un-coördinated. Only seldom could one have encountered a joint work by a geologist, archeologist, botanist and paleontologist for the purpose of attacking a certain selected problem. But now, when the considerable economic and scientific importance of the Quaternary deposits became obvious, their systematic study became obligatory for all agencies in the country which are entrusted with geological research.

It was soon realized that the existence of only one Committee for the study of the Quaternary was insufficient. And so, even in the first years of the third "Five-year Plan," there were organized special Quaternary divisions at the Geological Committee in Leningrad, and at the Geological Institute of the Academy of Sciences of the U.S.S.R. A Special Quaternary Committee was organized at the Ukrainian Academy of Sciences, and a large scale work on the Quaternary took place under the auspices of the Byelorussian Academy of Sciences. The modest scientific periodical which has been published under the name of "The Bulletin of the Quaternary Committee" was transformed into the imposing "Trudy (Traveaux) of the Quaternary Committee," in which large monographs are now being published.

The study of the Quaternary in the territory of the U.S.S.R. assumed still wider development after the Second Conference of the International Association for the Study of the Quaternary Period, in the fall of 1942 at Leningrad. That year, which marked the beginning of the fourth "Five-year Plan," was also distinguished by the publication of the first map of the

Quaternary deposits of the European part of the U.S.S.R. and the regions adjacent to it, on the scale of 1:2,500,000, edited by S. Yakovlev.

For the opening of the Second International Conference an account was taken of the accumulated knowledge in the various aspects of the Quaternary history (stratigraphy, fauna, flora, fossil man) and a special large exhibit was organized at the Quaternary Division of the Academy of Sciences (J. G. N.-A.N.-S.S.S.R.) ; the members of the Conference acclaimed it the best exhibit ever made on the history of the Quaternary period. The Presidium of the Academy resolved to make it a permanent exhibit, and now it is a cherished possession and the pride of the Geological Institute of the Academy of Sciences.

At the meeting of the Conference there were reached various important decisions about the organization of a Soviet section of the International Association for the Study of the Quaternary (INQUA), and Academician J. M. Gubkin was appointed its chairman.

In the course of three years, between the 2nd and 3rd conferences of the INQUA, the Editorial Committee for preparation of the International Quaternary Map of Europe and the Soviet Section of INQUA have organized 46 expeditions in various regions of European part of the U.S.S.R. and Caucasus Thirteen of these expeditions were engaged in mapping the enormous territory of the Northern region, Karelia, and the Kolsky peninsula. It is important to point out that these expeditions worked according to a planned program, and used a uniform standardized legend and scale for mapping, which is a rare instance of a coördinated investigation over a territory of such immense size.

Alongside of the development of cartographo-geological undertakings the Soviet scientists succeeded in exploring the other aspects of the Quaternary history, especially fossil man, flora, fauna, tectonics, and placer deposits of the precious metals and diamonds.

Cartographo-Geological Accomplishments: As the result of an extensive work on the organization of the cartography of the Quaternary, for the success of which we are indebted to Professors S. Yakovlev, G. Mirchink, and others, we have now at our disposal six sheets of the International Quaternary map of Europe: 12th, 27th, 19th, 20th, and 13th, four of which are

published and two in press; they cover almost the whole plain of the European part of the U.S.S.R. on the scale of 1·1,500,000.

Besides the Quaternary maps of the European part of the U.S.S.R. on scales 1.1,500,000 and 1 2,500,000 we have now some maps of larger scale for separate regions and republics. For instance, for the Ukrainian SSR we have a Quaternary map on a scale of 1:500,000,000; for Moskovskaia, Ivanovskaia, Kalininskaia, and Western Oblasti (regions)—maps on the scale of 1·420,000; for Leningradskaia region and Karelian ASSR on scale of 1:1,000,000; and for some separate regions of the North on scale of 1:500,000. Besides, some regions have also still larger, more detailed maps, which were made in connection with certain practical problems at the request of various organizations.

Less satisfactory is the situation in the Caucasus, the Urals and the Asiatic part of the U.S S.R. For these territories we do not have as yet summarized Quaternary maps, even on a small scale. However, maps on the scales of 1:1,000,000 and 1:1,400,000 exist for some large regions of Western Siberia and Kasakhstan (Prepared by H. Ber, L. Vvedensky, V. Gromov, N. Pravoslavlev, and others). Such were made, for instance, for the Omsko-Barabinsk region, for the central parts of the Western Siberian plains (basins of rivers Vah, Yugan, and others), for the regions along the Ob and Irtysh rivers, the Kulundisk Steppe, and others.

Considerable cartographic material has been accumulated for the Southern and Middle Urals, as the result of systematic work under the direction of I. Sobolev of the Ural Geological Department, and A. Burov of the Ural Diamond Expedition, and also as the result of works of the "Uralzoloto" Trust and of the Complex Ural Expedition sent by the Academy of Sciences of the U.S.S.R. Mention should be made also of considerable development of geomorphological mapping, on a variety of scales, of various territories of the Soviet Union, particularly that of the Middle Urals, which is being made by the Ural Diamond Expedition since 1938 on the scale of 1:300,000, simultaneous with the mapping of unconsolidated Mesozoic-Cenozoic deposits (by I. Krasnov, K. Nikiforov, L. Shorygin, and others). The material accumulated to date permitted the start of a summarized geomorphological map of the Urals on

the scale of 1:500,000, and an idea of the preparation on the same scale of a map of unconsolidated Mesozoic - Cenozoic deposits is being considered. In the domain of geomorphology mention should be made of the work of the Institute of Physical Geography under the direction of A. Grigoriev, and of the first summarized geomorphological map of the U.S.S.R. prepared by I. Gerasimov and K. Markov, the members of the Soil and Geographical Institutions of the Soviet Academy.

Economic Minerals: Thanks to the explorations by E. N. Stchukina in Altai, K. V. Nikiforova and E. N. Shchukina in Southern and Central Urals, G. Mirchink and Gurachek at Aldan, and G. D. Karamysheva in Salair and Urals, there were noticed in 1938 some regularities in the distribution of placer deposits of cassiterite and gold, which are connected with an ancient buried hydrography. Quite independent from this work, it has been established through the extensive collective explorations of the Ural Diamond Expedition, particularly by the geomorphologists D. Borisov, J. Krasnov, N. Kind, N. Vvedenskaia, and also by V. Trofimov, N. Gerakov and others, under the general leadership by G. Volosiuk, that all the economic, diamond placers are connected with the unconsolidated Mesozoic-Cenozoic deposits, and are enriched through repeated redeposition in the alluvium of the ancient hydrographic net, or in the karst gorges and ravines of various ages. Therefore, the study of the regular distribution of the placer deposits, the finding of the mother rock of the diamonds, and the establishment of the directions and routes of deposition, is connected directly with the reconstruction of the ancient hydrographic and ravine-canyon systems. Thus the reconstruction of these ancient systems, which is based entirely on the methods worked out by the Quaternary specialists, has a fundamental significance in the organization of exploratory-prospecting work for the placers. Similar regularities are also observed in some of the platinum placers of the Urals (V. Trifonov, J. Rozhkov).

It is appropriate to notice here the preparation of the first maps of a kind which indicate the diamond placers of the Middle Urals on scales of 1:500,000 and 1:200,000; they are being edited by the chief of the Diamond Expedition M. Shestopalov and the chief engineer of same expedition A. Burov. This map is based to a considerable extent on the work of the Quaternary geologists, who also prepared the map of the bed-

rock and of Pleistocene thicknesses of the Moscow region in connection with the study of the distribution of the Quaternary waters (L. Shorygina); and the maps of the loess-like rocks of the Asiatic part of the U S.S R. in connection with investigation of the geologic-engineering properties of the loess-like rocks (by A. Moskvitin and K. Pestovskii). There are also other maps on the Quaternary geology and geomorphology, which were prepared in connection with exploration for economic minerals, by special requests of numerous economic organizations.

Fossil Man· The Soviet explorers made considerable progress in the study of the man of Paleolithic and Neolithic ages. A mere list of Paleolithic stations discovered and investigated in the last 25 years would take too much space; their total number since the October Revolution increased to 250, which is more than ten times the number of the previously known stations,—and each new discovery of a Paleolithic station is a major event in the study of the Quaternary in general and of the history of the material culture in particular.

Some of the most important researches are as follows. The investigations of the Paleolithic of Enisei River (by N. Auerbach, V. Gromov, G. Sosnovskii, of 1923-25), which resulted in the establishment of three groups of stations of different ages in the second half of the upper Paleolithic. The excavations of the Aurignacian-Solutrean station of Malta near Irkutsk (J. Gerasimov), which yielded a series of remarkable objects made from mammoth tusks (female figurines, birds, mammoth engraving, etc.). A communication was just received that A. P. Okladnikov found on the Lena River a station of Paleolithic culture with a sketch of a mammoth figure. The discovery of 1939 by M. Talitskii of the Mousterian type of flints (a sharp point and chips) and of an upper Paleolithic station at the mouth of Chusovaia River in the Urals, the excavations of which were continued in 1942 by M. Griaznov and A. Jessen. The numerous explorations by P. Efimenko and S. Zamiatin near Voronezh and Lipetzk on Don River. The widely and thoroughly organized excavations of 1939 in the Paleolithic of Desna River which were conducted under the direction of M. Voevodskii. Because they were conducted in connection with detailed geological investigations of the local Paleolithic, they resulted in discovery of a Mousterian type of culture under a moraine of a maximal glaciation (V. Gromov, V. Khokhlovkin). The numer-

ous systematic excavations of Paleolithic cultures in Crimea under the direction of G. Bonch-Osmolovskii, which resulted, not only in the establishment of a succession of cultural strata from the well developed Mousterian (or, as Bonch-Osmolovskii thinks, from an undetermined pre-Mousterian stage) to epi-Paleolithic inclusive, but also enriched the science of Anthropology by a discovery of a Neanderthal burial. The remarkable discoveries of 1934 by S. Zamiatin of the numerous Paleolithic stations along the Black Sea coast of the Caucasus, proved the presence in the U.S.S.R. of remains of the Clactonian stage (Lower Paleolithic). There should be mentioned also the works on the Paleolithic by O. Bader and S. Bibikov in the Crimea, and by M. Rudinskii in the Ukrainian S.S.R. which helped much in the establishment of periodicity of Paleolithic cultures in the territory of the U.S.S.R., and in putting of archeological foundation under the stratigraphy of the Quaternary deposits.

Some of the above listed stations, such as Afontova Mound II on the Enisei River below Krasnoiarsk, at Malta near Irkutsk, the groups of Kostenkovsk stations on Don River below Voronezh, and at Kiik-Koba in the Crimea, have already received a worldwide renown because of the importance of the discoveries connected with them and because of the exemplary way in which the investigations were conducted. The work on the geology, fauna, and flora of the Paleolithic which not infrequently was conducted simultaneously with the archeological investigations, could be set apart into a special category of research.

The vast material from all these Paleolithic investigations was monographed by V. Gromov (1938-39), and he proved that the middle Paleolith (Mousterian) belongs to a geological time preceding the maximal (Riss) glaciation of Eurasia and corresponds to the first half of it, while the upper Paleolithic (Aurignacian, Solutrean and Magdalenian) fall in the second half of Riss, Riss-Würm, and Würm time. Thus it was proved that Paleolithic stations have much greater stratigraphic significance than usually supposed.

Quaternary fauna· Since the October Revolution a considerable success was also achieved in the study of mammals and marine invertebrates. Much less is known about the Quaternary avifauna and fishes, the study of which began essentially

since the second "Five-year Plan," when A. Tugarinova started her work on birds and M. Tikhii his work on fishes.

Among the investigations on mammals there should be mentioned first of all the numerous descriptions by M. Pavlova, which she began far back before the October Revolution and which have been carried on by her with variable intensity throughout her whole life.

In recent time the work by M. Pavlova was continued and developed by V. Gromov, E. Beliaev, J. G. Pidoplichka and others. The enormous material, which accumulated in the course of the first three "Five-year plans" was sufficient for the studies in both stratigraphic and purely paleontologic directions. Among the accomplishments of purely paleontological aspect are the fine monographs by V. Gromova on the natural history of the subfamilies Bovinae and Caprovinae, and of the family Equidae, which throw much light on the ancestral history of the domesticated animals. There should also be mentioned the synoptic work by J. G. Pidoplichka on the history of the Ukrainian fauna. Finally, mention should be made of the first attempt by V. Gromov to reconstruct the history of the Quaternary fauna of the U.S.S.R. on the basis of phylogeny and stratigraphy. The following are the characteristic faunal complexes for the major stratigraphic units of the Quaternary: (A) *Taman* (Tamanian) which stands at the border between Pliocene and Lower Pleistocene, and includes a late form of *Elephas meridionalis*, *Elasmotherium caucasicum*, *Equus* sp.; the latter is a characteristic Tamansk form, the teeth of which still preserve some characters of the Pliocene *Equus stenonis*. (B) *Tiraspol* (Tiraspolian)—Lower Pleistocene or Mindelian, with *Elephas wüsti*, *Bison schoetensacki*, *Alces latifrons*, *Cervus* (*Megaceros*), and others. (C) *Hozar* (Hozarian)—Mindel-Riss and Ranneriss, with *Elephas trogontherii* (Pole), *Bison priscus longicornis*, *Megaceros germanicus*, *Camelus knoblochi*, and others. (D) *Upper Paleolithic*—Riss, Riss-Würm, and Würm, with *Elephas primigenius*, *Rhinoceros antiquitatis*, *Megaceros hibernicus*, *Vulpes lagopus*, *Lemmus obensis*, *Myodes torquatus*, *Rangifer tarandus*, and others. Within this complex may be further segregated the faunas of Aurignacian, Solutrean, Magdalenian and Epipaleolithic ages. (E) Recent (Holocene), some of the animals of which had different areal distribution at the beginning of the epoch.

A closer study of the faunas of the Paleolithic stations has shown that the Mousterian fauna is but an impoverished Hozarian fauna. It is characterized by the presence of *Elephas trogontherii*, the abundance of a large bison, which is probably close to *Bison priscus longicornis*, the gigantic deer, and also the wolves, foxes and other animals, which are common in the later time. It is characteristic that at this time the reindeer (kodak) appeared even in the southern part of the Russian Plain. In the cave stations of Crimea and Transcaucasus the Mousterian strata are well characterized by the numerous remains of the cave bear and the cave hyena. At this time in Crimea (Kiik-Kiba) appeared the reindeer and wooly rhino (*Rhinoceros antiquitatis*), and among the birds—the apline chough which indicate a cooling that can be the result of the advancing Riss glaciation. In general the Mousterian (probably late Mousterian) animals appear as a stable faunistic complex, which may be called the Mousterian fauna. Its distribution is very extensive. The recent discoveries in the Urals show that here too the Mousterian fauna preserved its fundamental aspects, except that in place of the giant deer, so numerous in the Crimea, there are encountered quantities of the remains of the noble deer, and there is also an admixture of the Asiatic elements.

Super-Paleolithic fauna: This fauna is a segregated and stable complex, which varies only in details, depending on geographic position, and it may be properly called the "Super-Paleolithic faunal complex."

In the Crimea we find the wild mountain goat, mountain sheep, cave hyena and cave bear, which are associated with the common Super-Paleolithic rhino, mammoth, bison, horse, and others. In the Transcaucasus, in the Baikal area, and along Yenisei River we find fundamentally the same Super-Paleolithic fauna with an admixture of some elements of the Asiatic fauna. Thus, beginning from Urals and eastward, *Capreolus pyrargus* displaces the European roe deer, and the Siberian maral displaces the noble deer of the Russian Plain; at Yenisei River there are added to them the siberian goat and argali; in the Baikal area —snowy sheep; and at Transbaikal the peculiar Asiatic antelope, *Spiroceros kiakhtensis*. Beginning with the western slope of the Urals the remains of the cave bear and cave hyena became gradually scarcer. In the Russian Plain there is a marked

absence of the Asiatic and mountain types of animals. One of the most characteristic peculiarities of the Super-Paleolithic fauna is the presence of cold-loving animals, and the general mixture of the representatives of the different zoological habitats, especially those of tundra and steppe. Thus, even in the Crimea, already in lower Aurignacian strata there appear such northern elements as the arctic fox, northern deer, polar lark, white partridge, grouse, and the chough. Their penetration to the south can be explained only as the consequence of the maximal, that is Riss, glaciation, because these occurrences represent the southernmost penetrations of the Arctic fauna known to us. The advancing ice-sheet pushed the inhabitants of the Russian Plain—the giant deer, saigak, horse, ox, rhino and mammoth—to the south, and to the southern mountains. There they became mixed with the Crimean aborigines, the goat and sheep. Thus they formed a peculiar "mixed faunistic complex," to which were added apparently also the last representatives of the cave hyena and cave bear. The same situation is encountered also in the southern Urals, Transcaucasus, Russian Plain, Baikal area, and southern and middle Siberia along Yenisei River. However, while in the caves of the southern Urals and Crimea we find some arctic fox remains mixed with numerous deer and horse and in the middle Ural even with the lemming,—in Transcaucasus the Riss refrigeration of Super-Paleolithic age has resulted on the one hand in penetration of the elk, (Navalishinsk and Akhshatyrsk caves near Sochi, Gvardjilas-Kalde, Sakajiia near Kutais) and the glutton, and on the other hand, in the descent toward the valleys of the inhabitants of the alpine and subalpine meadows the promethean mouse and gazel (Guardjilas-Kalde, Sakajiia). At Transbaikal and along the middle Yenisei River we find such typical steppe dwellers as the giraffe and numerous remains of the arctic fox, which lived there with mammoth, rhino, ox, deer, and horse. In the Russian Plain the "mixture" of the faunas was particularly conspicuous at the time of melting of the ice-sheet (Riss) during the Aurignacian-Solutrean stage, when the deer, horse, ox, and others moved toward the space vacated by the ice-sheet and met there the lemming, arctic fox and other arctic animals already inhabiting it. The most typical representative of the Super-Paleolithic fauna of this time are the mammoth, rhino, short-horned bison, northern deer, musk-ox,

arctic fox, lemming, and horse. They are accompanied by the large carnivores (wolf, bear, cave lion), by steppe elements (jumping hare (jerboa), and marmot), and by the forest dwellers (muskrat and beaver). But the giant deer, cave hyena and cave bear are absent here, and the giraffe and ox are also very rare. However, in the extra-glacial region especially in the stations of the end of the Super-Paleolithic, the ox was not rare (Dubovaia Balka near Dniepropetrovsk, Amvrosievka near Mariupol).

It is possible that the primitive ox (*Bos primigenius*), also lived in the forests of this time, though as yet its remains are unknown in western Europe, not counting the group of Dniestr River stations.

Such are the fundamental features of the Super-Paleolithic faunal complex which lived from the maximal (Riss) glaciation to the late Würm inclusive. However, in the course of this time the Super-Paleolithic fauna did not remain unchanged. Although for the whole territory of the U S.S.R. these changes seem to be insignificant, they can be recognized in its separate regions where the paleolithic data are known Thus, in the Crimean Aurignacian fauna the northern forms were diminishing in the upper Aurignacian,—a fact which is likely connected with the beginning of waning of the Riss ice-sheet. On the contrary, in the Russian Plain, which is near the center of the glacier, the arctic species are widely developed even in Solutrean, and the mammoth is quite characteristic among the large, thick-skinned animals of the stations of this age. It appears (though this needs confirmation) that by the end of the Solutrean age, and especially at the beginning of Würm, within the glaciated region of the Russian Plain, the percentage of the comparatively warmth-loving animals is diminishing. A plausible explanation of this could be as follows: the warmth-loving animals, which moved here following the retreating tongues of the Riss ice-sheet, could not, however, find a suitable situation for a long subsistence, and, as they decreased considerably in the number of individuals, they were not able to survive the Würm age; thus the Wurm fauna assumed a more nearly uniform and stabilized, colder aspect, as compared with the preceding Riss-Würm fauna.

The rhino and lemming which are among the characteristic representatives of the earlier stages of the super Paleolithic,

disappear by the beginning of the Magdalenian, and in the late Magdalenian the mammoth and arctic fox are absent. It is however, quite obvious that it is impossible to recognize here a succession of a "cold" fauna by a "warm" one.

About the same successive changes can be recognized also in the Yenisei River stations. When taking into account, on the one hand, the geographic position of the stations, and, on the other hand, their faunal assemblages, it is permissible to distinguish here too the faunas of Aurignacian, Solutrean, and Magdalenian ages.

Epi-Paleolithic fauna: The Epi-Paleolithic fauna, which is known to us largely from the Crimean stations, differs considerably from the Super-Paleolithic fauna by the absence of a whole group of the extinct species, such as the cave hyena and cave bear, giant deer, rhino, mammoth, and other, and also by the absence of the arctic forms. The Epi-Paleolithic fauna consists only of living species, but these occupy different areas of distribution in comparison with that in the Recent time. Characteristic of this fauna is the presence of the domestic dog, and for the Crimean fauna also the penetration of the European roe deer.

Thus the faunistic data indicate a tieup of the history of the upper Paleolithic with the duration of time from the maximal glaciation (Riss) almost to the end of the second half of Würm; and the history of the middle Paleolithic, with the end of Mindel and the first half of Riss.

None of the above described animal complexes is repeated in the Quaternary history; but they succeed each other in time, and are clearly genetically interconnected. As they gradually degraded under the impact of changing situation they disintegrated into component parts, some of which died out, while the others, in a somewhat changed form, entered into new, gradually formed biocenoses. This history is particularly well traceable, for instance, in the Bovineae and Elephantidae. The Recent fauna, when compared with that of the Quaternary, is considerably impoverished, but its roots penetrate not only into the earliest Quaternary but descend even deeper into the Tertiary, where we find not a single living species at all.

It is very significant that in the history of the fauna the

representatives of the arctic animals appear only once in such southern latitudes, which now they never reach. They do so at the beginning of the second half of the Quaternary. It is only natural that this observation brought about a skeptical attitude (especially from the biologists), toward the theory of repeated glaciations, which is now dominant among the Quaternary geologists. The existence of this difference of opinion, however, does not detract from the established stratigraphic value of the Quaternary mammals, which is now admitted by even the most extreme adherents to the theory of repeated glaciations.

The reconstruction of the history of the Quaternary invertebrates is at the present less complete. Thanks to the works of M. Zhukov, A. Eberzin, L. Davitashvili, A. Arkhangelskii, N. Strakhov, and others, we are now well acquainted with the Chandinsk, Balinsk, Paleoevksinsk, Uzunlarsk, Karangatsk, Neoevksinsk, Paleochernomorsk and Hozarsk faunas, which succeed each other in the Black Sea and Caspian basins from the end of the Pliocene through the whole Quaternary. Although these studies have an undoubted stratigraphic significance, the history of these faunas as known at the present, concerns only the Caspian and Mediterranean forms. The changes in these faunas were explained as a consequence of the repeated freshening and salinification of the Black and Caspian seas, which, in turn, were essentially the consequences of tectonic movements. Only very recently some attempts have been made (by M. Zhukov) to interpret the history of the marine invertebrates from a phylogenetic point of view. The work by M. Lavrova on the fauna of marine mollusks has an equal stratigraphic importance for the division of the upper Quaternary in the north of the European, and, to some extent also, of the Asiatic parts of the U.S.S.R. However, the oldest of the faunas known to us, the so called Boreal fauna, is customarily assigned to Riss-Würm age.

In spite of a considerable amount of work already done (J. Danilovskii, and others) on the fresh-water mollusks, their study apparently has not progressed beyond the stage of accumulation of material. Therefore, their stratigraphic significance is as yet not very great.

Quaternary flora: The first discoveries of the Quaternary flora (Troitzk deposits) were made in the nineties of the last century. However, the paleobotanical investigations attained

some prominence only after the October Revolution, at the beginning of the second "Five-year Plan." At that time there were discovered in the territory of the European Plain a series of buried bogs with the seeds of *Braseania*, and their study was initiated by V. Dokturovskii and G. Mirchink. Since that time the findings of the fossil floras has increased greatly, and at the present the number of the known localities with the Quaternary flora probably is near a hundred. The broadening of our knowledge of the Quaternary flora is to a considerable extent due to the application of the spore and carpological analyses, which have been worked out by V. Sukachev, V. Grichuk, T. Pokrovskaia, P. Nikitin, E. Grunewald, and others. Thanks to their work, and also to that of I. Palibin, A. Kryshtofovich, S. Tiuremnov, and others, the essential course of the development of the Quaternary flora of the U.S S.R. may be already outlined, although the studies in the different territories of the Soviet Union are far from being equally advanced. Thus, it is possible to state with some confidence that at the beginning of the Pleistocene the flora of the U.S.S.R. was fundamentally close to that of the Recent, although the early distribution of its forms was substantially different. For instance, in the eastern Caucasus there were growing forms which are now inhabiting the western Caucasus, while in the forest-steppe region there was taiga together with the forms which now grow in Siberia. Besides, the lower Quaternary flora included several American elements and a series of extinct forms. However, even at that time the flora had an appearance indicative of a moderately-warm and moist climate, comparable to that of the present, as some of the still earlier evergreens disappeared even in the Caucasian Mountains.

Thus, as in the case of the mammalian fauna, the refrigeration at the beginning of the Pleistocene is noticeably indicated in the flora. The plant-bearing deposit of the Lukhvinsk locality on Oka River, which the advocates of the repeated glaciations classify as Mindel-Riss, contains the most typical and undoubtedly the most ancient Pleistocene flora. This flora consists of fir, pine, birch, and, among the broad-leaved forms, elm, beech, hazelnut, and also *Euryale ferox*, *E. europaea*, *Trapa natans*, and others, which indicate a warmer and wetter climate. Especially interesting is the find of *Euryale*, which now grows in Eastern Asia, beginning with Manchuria and far-

ther to the south. A few investigators (G. Mirchink, V. Dokturovskii, S. Yakovlev) consider some other localities to belong to the same age, although in these the extinct forms are absent, particularly *Euryale*. Another locality for the flora of the same age is indicated by P. Nikitin in the Voronezh region (at Demshinka village) where he found the remains of the American fern *Azolla* and three species of Nymphaeaceae and Naiadales, —but the age reference of this flora must be verified by an additional, detailed geological study.

The next, or the so-called "Brasenia flora," is known from a larger number of localities. It contains, as its most characteristic element, *Brasenia purpurea* (now living in the southernmost part of the Russian Far East, in Manchuria, Japan, Africa, and Australia), together with *Aldrovanda vesiculose*, *Trapa natans*, *Najas marina*, and others. Much farther to the north and east of the European part of the U.S.S.R. extended at this time such plants as *Acer tataricum*, *Tilia platiphyllos* (north to Moscow), and elm (to Galich). It is possible that the beech also extended farther to the north at this time. This flora, which according to the estimate of V. Sukachev, consists of upwards of 125 species of phanerogams and over 25 species of mosses, is usually referred to the Riss-Würm. No intermediate flora between the one with *Brasenia* and that with *Euryale*, which, if the pluri-glacial theory is correct, should have had an arctic aspect, has been discovered. On the other hand, an arctic flora is known from the deposits which, according to the accepted stratigraphy, are above the beds with the Brasenia flora and belong to the last Würm glaciation.

The post-Glacial history of the forests has been worked out in great detail, especially for the north of the European part of the U.S.S.R.

The flora of the Asiatic part of the U.S.S.R. is not so well known as that of the European part, but in this territory too the general trend of change in the flora was apparently the same; the inevitable refrigeration and the extinction of the warmth-loving forms.

The investigations of the marine and fresh water diatoms should also be mentioned. This branch of paleobotany developed considerably only during the last two "Five-year plans," thanks to the work by V. Sheshukova, A. Jousé, and, especially, V. Poretski. Although remaining, as yet, in the stage of accu-

mulation of record, the studies on the diatoms even now help to solve some stratigraphic problems.

Buried Soils: The buried soils are now being used in stratigraphic schemes by many Quaternary geologists, but as yet, no generally agreed method for their study has been developed. The undoubted considerable stratigraphic significance of these soils has been proved, for instance by V. Krokos, who differentiated with their help the loesses of the Ukraina. They were also similarly used by A. Moskvitin, and G. Mirchink, while E. Shantzer, used them for the deluvial deposits along Volga River. However, their stratigraphic significance has been infrequently overestimated: for instance when comparing the buried soils in the forests of Dniepro-Petrovsk with those along the Azov Sea shores. The use of the buried soils at the present apparently is limited primarily for rather local correlations, as they are useful horizon markers within limited territories only. They are also utilized for some paleogeographic reconstructions.

Quaternary Tectonics: The study of the orogenies which undoubtedly played a considerable rôle in the history of the Quaternary, emerged from the stage of mere accumulation of data only in the last decade. The syntheses of the Quaternary orogeny by G. Mirchink for the territory of the U.S.S.R., V. P. Nekhoroshev for Altai, N. Sokolov and G. Bystrov for Siberia, S. Schultz and G. Skvortsov for Tian-Shan, L. Vardaniantz, V. Rengarten and A. Reingard for Taman peninsula, and also by many other investigators, show that the studies of the Quaternary tectonics entered the stage of summing up, though, at the present, chiefly for the separate territories.

These investigations established the existence of the lower Quaternary orogenic phase, which left its definite mark, in the form of both folds and faults, in the mountains of the European U.S.S.R., in the Caucasus, and, probably, in the Urals, Siberia and Central Asia. In geomorphic platforms these tectonic moves were expressed by epeirogenic uplifts and sinkings: for instance the uplift of the Ufimian plateau, of the Azov-Podolsk horst, the lowering of the North-Ukrainian depression, and others. To this orogenic phase, which Mirchink proposes to call Bakinsk, are probably connected the considerable rejuvenation of the river systems in the Central and Southern Urals, in the northern Caucasus and Transcaucasus, and in the basins of Oka River, the Volga River and a series of other places. Some explorers (L. Vardaniants) prove, that besides the Bak-

insk, an independent upper Quaternary orogenic phase has had an equal significance. However, even if the existence of this phase shall eventually be proved for the mountains, it affected the continental platforms only slightly, as G. Mirchink thinks; in this respect it differs substantially from the Bakinsk phase.

The Caucasus has been studied tectonically particularly well. According to the data by Reingard the head waters of the Kuban, Teberda, and Ullu-Kom Rivers have been elevated up to 1200 meters since the time of the Mendelian glaciation, and up to 400 meters since that of the Riss, while Vardaniantz claims still greater elevations.

In central Asia, where the magnitude of the Quaternary movements reaches many hundreds of meters, some special investigations of the Quaternary elevations were undertaken in connection with various engineering constructions (Chirchikstroi). Taking account of the Quaternary orogenies has a considerable importance in working out of the greater Volga problem, which involves construction of dams and other hydraulic structures, they are also important in estimation of the water balance of the Caspian Sea, in organization of melioration works at Kolhida, and elsewhere. Thus the Quaternary tectonics, besides their purely scientific significance, are gaining year by year in practical importance, which, of course predetermines their further intense and useful study.

Since the October Revolution the stratigraphic and related geomorphologic investigations, which have already been mentioned, were particularly successful. At the present we are entering the stage of building a general stratigraphic synthesis which is based on the accomplished studies of various regions; but this is being undertaken only for the European part of the U.S.S.R. which has been more nearly completely studied than the Asiatic part. However, even for the latter enormous territory we have already a series of summaries by V. Obruchev, J. Edelshtein, and others; thus even here we are on a way toward establishment of broad paleogeographic reconstructions The first step in this direction was made by I. Gerasimov and K. Markov, who, in their monograph on the Glacial Period in the Territory of the U.S.S.R. (1939) discussed a series of most fundamental problems which concern the geological history of the Quaternary, and give a first paleogeographic reconstruction for the whole U.S.S.R. Being the first attempt of

such magnitude it is naturally not without some substantial shortcomings, but we cannot discuss them here. One of the most serious discords with the existing stabilized views on the simultaneity of the glaciation of Europe and Asia, is the defense by these authors of heterochrony of the glacial phenomena in western Europe and Eastern Siberia, and of the consequences which follow from this view.

The following main conclusions, which are based on the stratigraphic studies of the Quaternary in the U.S.S.R., seem to reflect in a general way, the fundamental views on the history of the Quaternary, which are shared by the majority of the investigators.

Ng_2^1L Pliocene.

The Günz glaciation is referred by some geologists to the Pliocene, but others place it at the beginning of the Quaternary, while still others doubt the existence even of traces of this glaciation.

Russian Plain. Ergeni Sands with *Equus stenonis* (Latnaia, Voronezh region).

Caucasus. Development of 175 meter gravel terraces with *Elephas meridionalis* on Kuban River. Khoprov sands with the fauna of *Mastodon arvernensis*, *Hipparion* sp., *Elephas* cf. *planifrons*, and *Struthio* sp., which are located between Rostov and Taganrog (Azov Sea shores).

Black Sea. Chauda Basin with *Didacna cazecae*, *D. tschandae*, and many varieties of Dreissensidae,—placed at the end of Günz or the beginning of Gunz-Mindel.

Caspian Sea. The closed, saline Apsheronsk Basin, with *Apscheronia propinqua*, *A. raricostata*, *Didacna* ex. gr. *intermedia*, and many varieties of Dreissensidae.

Ng_2^3M. Upper Pliocene.

Some investigators regard it as a Gunz-Mindel interglacial epoch.

Caucasus. The origin of the escarpment of 175 meter terrace. Travertines of Lermontov bluff at Piatigorsk, with *Elephas meridionalis*. Terraces of Podkumok 120 meters high. Skifian clays of Azov shores.

Russian Plain. Syrt clays of Trans-Volga Region.

Central Urals. Brownish red clays with quartz gravels upon

the erosion terraces which are above the bottom lands. Closing stage of accumulation of the tertiary gravels (Imennov gravels) in the basin of Tura and Isa Rivers, and in Visim depression. The sites with *Elephas meridionalis* in southern Urals (Kvarkeno).

Siberia. Ishim fauna (?)

Q_1M. Lower Pleistocene (Mindel).

Mindel glaciation. Some investigators refer this glaciation to the Pliocene; the majority, however, consider it of Quaternary age and draw the Pliocene boundary below it. Still others, while agreeing with this boundary, do not consider the existence of this glaciation proved. On the other hand, a few other, contrary to the opinion of the majority, consider the Mindel as the time of maximal glaciation.

Caucasus. The origin of the escarpment of the 100 meter terrace (at Batalpashinsk) and the deposition of the gravels upon it. The 100 meter terraces of Caucasian shores of Black Sea, which contain Clacton artifacts.

The initiation of accumulation of *Paludina* sands with *Bison schoefensacki*, and *Elephas wusti*, by the end of Mindel, at Taganrog.

Black Sea. Paleoevksin basin with *Didacna pontocaspia*, etc., at the end of Mindel to beginning of Mindel-Riss.

Caspian. Baku Basin, with *Didacna rudis*, *D. carditoides*, *D. parvula*,—*end of Mindel.*

Russian Plain. The glacial sheet reaches to 50° of northern latitude. The deposition of the third (from the top) horizon of loess in the Ukraine and other periglacial regions. Modeling of the recent valleys of the Dnieper and Don Rivers by the glacial streams The initiation of the deposits of Piviha Mountain and Tiraspol gravel with *Paludina diluviana*, *Elephas wüsti*, *Cervus verticornis*, etc., at the very end of this epoch. Swamp-mud formations in lower Volga Basin with *Equus* sp., *Rhinoceros mercki*, *Elephas antiquus meridionalis*, *Elephas* cf. *trogontherii*, large Unionidae, *Paludina*, etc., Kosozh and Sengil series.

Urals. The third terraces above the bottom lands in the basin of Tura and Isa Rivers. The initiation of the phase of a considerable rejuvenation of many river valleys. Erosion of the Tertiary deposits which fill the large meridional depressions

(for instance Tura depression). The fourth terraces in the lower Chusovaia River and the third terraces along many other rivers.

Siberia. Sculpturing of the escarpments of 100 meter terraces of Angara and Yenisei Rivers. Deposition of the fine mica-bearing blue sands with *Elasmotherium* sp. at Pavlograd. The gravels of the upper terrace of Ishim River with *Alces latifrons*.

Q^1_{II} Middle Pleistocene (Mindel-Riss).

The majority considers this a Mindel-Riss interglacial stage. Here belongs the Baku (Bakinsk) orogenic phase.

Caucasus. Sculpturing of the escarpment of the 100 meter terrace at Batalpashinsk. Completion of the deposition of the Paludina sands with *Elephas wusti* at Taganrog in the first half of this epoch. Lower (or the third from the top) horizon of the buried soils on the Azov shores, with numerous remains of Equidae and Bovinae; and in its animal burrows, *Cricetus cricetus* and Spalacidae (in the first half of Mindel-Riss); also the stations of the Sutierian artifacts (*Lakedomonovka*) and of flint chips (*Bessergenovka*). The 60 to 40 meter terraces of Caucasian shores with Mousterian artifacts.

Black Sea. Continued existence of the Paleoevksinsk basin (the first half of Mindel-Riss).

Caspian Sea. The Baku transgression, which ends at the initiation of the Mindel-Riss epoch. The connection with the Paleoevksinsk basin and, through Uzboi, with the Sarykamysh lake-sea. Khozar transgression with *Didacna* ex. gr. *crassa* Nal. (non Eichwald), *Dreissensia* ex. gr. *caspia*, *D. celekenica*, *Unio*, Dreissensidae. Along the shores of the limany—the Khosar fauna with *Elephas throgontherii*, *Bison priscus longicornis*, etc. Connection with Black Sea through Manych.

Russian Plain: Accumulation of the gravels on the banks of Kama River, and at Undory and Bekhtiazhka on the Volga River, with the same Khozar fauna.

The chain of the connected lakes along the Eastern European platform, which are fresh in the east and saline in the west—, i.e , the Mediterranean, Black Sea, Caspian and Sarykamysh.

Urals: The lower part of the alluvium of the two upper terraces in the mountainous part of the Urals, and the 2nd and 3rd terraces of the Ural foothills (Fore-Urals).

Siberia: Deposition of the gravels with the Khozar fauna in the valley of Irtysh River between Pavlodar and Omsk.

Q^{2}_{III} Middle Pleistocene (Riss Glaciation).

The majority consider it the epoch of maximal glaciation. Some refer the first traces of glaciation to the very beginning of the Quaternary.

Caucasus: The deposition of the loess-like silts above the Mindel-Riss soil (shores of Azov Sea). The accumulation of 40-50 meter terraces at Batalpashinsk, the second (from the top) horizon of the gravels at Krasnodar (the submerged terrace). The remains of *Ursus spelaeus rossicus* Borissjak of the Ukrainian loesses. The marginal moraines of Tzebelda at 400 meters of elevation.

Formation of the marginal moraines between the stations Kumarinskaia and Georgievsko-Osetinskaia. Akhtyrskaia settlement at Sochi of Mousterian age.

Ilsk settlement of the late Mousterian epoch at Krasnodar, with *Elephas primigenius*, *Bison priscus*, *Ursus spelaeus*, etc.

Black Sea: Uzunlar basin with *Mytilaster monterosatei*, *Cardium edule*, *Syndesmya ovata*, etc.

Russian Plain: The two tongues of the ice sheet, one along the Don and the other along the Dnieper River, reach the latitude of 50°. The accumulation of 50-60 meters river terraces. Formation of the second (from the top) horizon of loess in the extraglacial regions of Ukraina under continental climatic conditions. Astrakhan horizon of the red clays on the lower Volga Basin. The upper horizon of the moraine in Byelorussia and the Moscow region. The upper moraine of Odintsov. The site with *Elephas primigenius* under the Riss moraine at Putivl, and also of the Mousterian scrapers at Pushkari on the Desna River. Mousterian settlement at Kodak on the Dnieper River (the initiation of the epoch?).

Siberia: The considerable glaciation of the bare rocky highlands of Eastern Siberia, the Altai and Saian. Formation of the stationary ice caps in the East (Yakutiia). The fusion of the Uralian, north Siberian, Novo-Ziemlian and Taimyrian glaciers in the Western Siberian lowland somewhat to the south of 60° northern latitude. The origin of a great lake or of a chain of lakes, which stretches to the south of the ice sheet and has been connected with the Aral-Caspian depression through

Turgai strait. The accumulation of the alluvium of the 40-50 meter terraces.

Urals: The moraine in the lower Chusovaia River, near Molotov City.

Q_{III}^{I} R W, Upper Pleistocene (Riss-Würm).

Caucasus: The formation of the escarpments of the 35-45 meter terraces of the Kuban River. The origin of the second (from the top) soil horizon of black earth type, and, in the lower places, of "low-land" type on the Azov Sea shores, with remains of Bovinae, Equidae, Spalacidae. The swamp deposits below Krasnodar City.

Black Sea: Karangat Basin with *Tapes calverti*, *Cardium tuberculatum* and others.

Russian Plain: The steppe zone generally coinciding with its present distribution. The buried peat deposits of Murom, Novye Nemykary, Loev, Drozhzhino, Potylikha, Galich, and others, with *Brasenia schroteri*, *Aldrowanda* and *Najas marina*. The formation of the escarpments of the 40-50 meter terraces. The process of normal soil development (the upper buried soil in the loesses of Ukraina). The boreal transgression in the north in the basin of White Sea with *Cardium edule*, *C. fasciatum*, *Corbula gibla*, *Nassa reticulata*, etc. In the Pechora area the same with *Cyprina islandica*, *Mactra elliptica*, *Cardium edule*, *Pholas*, etc.

The lower *Yoldia* transgression in the basin of Vaga and Onega Rivers.

Settlements of Aurignacian-Solutrean stage in Ukraina and the Voronezh region.

Siberia: The transgression observed at the mouths of the Ob and Yenisei Rivers, with *Cyprina islandica*, *Mytilus edulis*, *Pecten islandicus*, *Balanus hammeri*.

Q_{III}^{2} Upper Pleistocene (Wurm).

The majority regards this as the last independent glaciation.

Caucasus: The glaciers did not descend at that time to the point of the confluence of the Kuban and Teberda Rivers. The accumulation of the gravels of the 15-20 meter terraces with *Elephas primigenius*, *Rhinoceros antiquitatis*, *Bison priscus deminutus*, etc. The upper horizon of the impure clays with the buried soil of the Azov Sea shores. The 20 meter terraces

of the Black Sea shores of the Caucasus, with the upper Paleolithic culture.

Black Sea: The freshened Neoevksinsk basin with *Micromelania caspia, Cardium edule, Monodacna pontica, Teodoxus pallasi*, and *Lithoglyphus caspius*, which is succeeded by the end of Würm time by the saline Paleochernomorsk waters with *Cardium edule, Mytilus galloprovincialis, Venus gallina, Tapes*, etc.

Caspian Sea: The Caspian becomes considerably reduced and loses its connection with Black Sea basin. At the end of the epoch the Khvalynsk brakish water transgression is initiated, which has the fauna of modern type: *Dreissensia polymorpha, D. rostriformis, Didacna protracta, D. praetrigonoides, D.* ex. gr. *trigonoides*, etc.

Russian Plain: The ice sheet reaches Minsk, Smolensk and Kalinin. The accumulation of the 15 meter terraces in the extraglacial region. The upper loess horizon of Ukrainia, with the horizon of the soil which separates it from the underlying loess. The thaw of the Würm ice sheet. Paleolithic settlements of Borshevo II; Magdalenian settlements.

Urals: The completion of the accumulation of the second terrace with the upper Paleolithic settlement of Talitsk at the mouth of Chusovaia River. These terraces are in the stage of being inundated. The accumulation of the first terraces above the present inundation.

Siberia: Local glaciation in the Mountains. In Western Siberia the ice sheet did not extend beyond the mouth of Irtysh River. The accumulation of the 15-20 meter terraces of Yenisei and Angara Rivers with the fauna of *Elephas primigenius antiquitatis*. The contraction of the ice sheet; the development of the forest-free spaces where now stretches the taiga of Central and Eastern Siberia. The upper Paleolithic settlement at Malta, on Belaia River near Irkutsk, with *Elephas primigenius, Bison deminutus, Vulpes lagopus, Rangifer tarandus, Rhinoceras antiquitatis*, etc., which belongs to the beginning of the glaciation in the basin of Angara River.

Upper Paleolithic settlements of the Yenisei River basin: Afontova Mound I, II, III, and IV; Kokorevsk group of settlements, Buzunovo, and others, with the fauna of *Elephas primigenius* in the earlier, and the same without the mammoth and arctic fox in the later settlements.

Moscow, U.S.S.R.

HOLCOCRINUS, A NEW INADUNATE CRINOID GENUS FROM THE LOWER MISSISSIPPIAN.

EDWIN KIRK.[1]

ABSTRACT. Ranging from the Devonian to the Permian are large numbers of inadunate crinoids which have a single plate in the posterior interradius. Many of these forms have been referred to *Graphiocrinus*. Several genera have been separated from this amorphous group in the past. In the present paper a new genus, *Holcocrinus*, is proposed for a compact group of species from the lower Mississippian. In addition to the described species here referred to the genus, there are several new species in the collections.

HOLCOCRINUS, new genus.

Genotype.—Graphiocrinus longicirrifer Wachsmuth and Springer.

Crown. Very high, compact. Owing to the great length and flexibility of the arms they frequently diverge somewhat, distad. The arms as measured range from 10 to 17 times the height of the dorsal cup. The largest crown measured has a height of approximately 120 millimeters. It is probable that some of the upper Burlington species were considerably larger than this.

Dorsal cup. Broadly turbinate to bowl-shaped in earlier species as seen. More narrowly turbinate to campanulate in most of the later species. In most species the plates are smooth. In some species the surface is granular, and there may even be irregularly disposed pustules. Among the later forms some species have depressed areas at their angles, which, in combination with those of contiguous plates, form pits. The plates of the cup are relatively thin.

IBB. The infrabasals are small but show clearly in lateral view.

BB. Post B broadly truncate.

RR. Large, articulating face extending the full width of the plate, linear. Suture gaping.

IBr. Axillary. Stout, constricted medially.

Arms. Long, relatively slender, flexible, with cuneate ossicles.

[1] Published with the permission of the Director, Geological Survey, United States Department of the Interior.

Pinnules long. In later species the brachials often bear spinous processes.

Post IR. The single anal plate is large, extending far above the level of the *RR.* It bears a single large tube plate on its distal face.

Ventral sac. The ventral sac is long, extending nearly to the tips of the arms or in some species beyond them. The structure of the sac is unusual. Generally it shows beneath the arms as a flattened structure composed of linear series of plates. It has been prepared in one specimen of the type species in considerable detail. Actually, the sac as preserved has the shape of a horseshoe in cross section. There is a deep ventral groove extending the length of the sac. Through lateral pressure the groove may be closed. Then the sac appears to be a tube with an oval or circular cross section. One assumes that in life the ventral groove was covered with pliant integument. In the proximal portion of the sac in the type species a vertical series of four large plates follows the anal plate. This series is flanked on either side by a row of smaller plates. The fourth plate of the median series bears two plates on its distal faces. This gives four vertical series of relatively large, thin plates. Distad each of the ventral, marginal rows breaks up into two rows of smaller plates. Proceeding distad the number of rows reverts to four, and near the tip, as preserved, there seem to be but three rows of plates.

Column.—The column is pentagonal in section in early species and pentagonal with concave faces in later forms. This applies to the proximal portion of the column. As is so often the case, distad the column becomes obscurely pentagonal in section and doubtless would be found circular in section in its distal portion. In some species the column bears cirri to within a short distance of the crown. The lumen is pentagonal in outline.

Distribution.—In America *Holcocrinus* is known in the Kinderhook group (Hampton formation of Laudon) and the lower and upper divisions of the Burlington limestone of the Mississippi Valley. It is doubtfully identified in the upper part of the Borden group of Indiana.

Relationships.—*Graphiocrinus* has a saucer-shaped or pateliform dorsal cup, with small *IBB* mostly concealed by the column and not visible in lateral view. The arms are stout and composed of brachials with parallel or slightly sloping faces.

The anal tube is long, circular in section, stout, tapering gradually distad, and composed of relatively heavy plates. The column is circular in section. It will be noted in the generic description of *Holcocrinus* given above that the genus differs to a marked degree from *Graphiocrinus* in all the characters noted.

There seems to be no known Devonian ancestor for *Holcocrinus*. The same is true for most of the lower Mississippian genera. In the upper part of the Borden group there is at least one undescribed genus that may have derived from *Holcocrinus*.

Remarks.—Excepting *Holcocrinus longicirrifer*, specimens representing species of this genus are very rare. In part at least this rarity is due to the fragility of the specimens. The cup, except in the later species, is usually flattened and the plates apt to be dissociated. The arms as a rule are only partially preserved.

Later finds in the upper Burlington limestone, particularly in the higher beds, have furnished new species of considerably larger size than any of the described forms.

Holcocrinus longicirrifer (Wachsmuth and Springer), new combination.

Graphiocrinus longicirrifer Wachsmuth and Springer 1889, p. 193, Pl. 15, Fig. 12; Pl. 17, Fig. 14.

"Kinderhook beds, Le Grand, Iowa." (Hampton formation of Laudon.)

Graphiocrinus longicirrifer Wachsmuth and Springer. Miller 1889, p. 251, Fig. 325.

Graphiocrinus longicirrifer Wachsmuth and Springer. Wachsmuth and Springer 1890, p. 193, Pl. 15, Fig. 12; Pl. 17, Fig. 14.

Graphiocrinus longicirrifer Wachsmuth and Springer. Laudon and Beane 1937, p. 260, Pl. 18, Figs. 8, 9; Pl. 19, Fig. 8.

Holcocrinus? nodobrachiatus (Hall), new combination.

Scaphiocrinus nodobrachiatus Hall 1861, p. 8.

"Keokuk limestone."

Scaphiocrinus nodobrachiatus Hall. Hall 1861a, p. 314.

". . . rocks of the age of the Keokuk limestone, Crawfordsville, Indiana." (Upper part of Borden group.)

Scaphiocrinus nodobrachiatus Hall. Hall 1872, Pl. 6, Fig. 2.

Poteriocrinus nodobrachiatus (Hall). Wachsmuth and Springer 1880, p. 120 (343).

This species is based on a segment of the arms of an inadunate crinoid. The specimen is now in the Springer collection in the United States National Museum. In all the large collections from the Crawfordsville region this seems to be the only specimen. The structure of the arms is consistent with that of *Holcocrinus* and with no other known genus. It is therefore referred to the genus with a query.

Holcocrinus smythi (Wright), new combination.

Graphiocrinus smythi Wright 1934, p. 258, Pl. 15, Fig. 8, Text-fig. 28.

"Supra-dolomite beds, Hook Head, Co. Wexford, Ireland."

This species, judging by the brachials, is based on an immature specimen. The dorsal cup is somewhat shallow for the genus, but the cuneate brachials, long, slender ventral sac, visibility of the *IBB* in lateral view, and the pentagonal column argue strongly for the inclusion of the species in *Holcocrinus.*

Holcocrinus spinobrachiatus Hall, new combination.

Scaphiocrinus spinobrachiatus Hall 1861, p. 8.

"Burlington limestone."

Scaphiocrinus spinobrachiatus Hall. Hall 1861a, p. 306.

"Burlington limestone, Burlington, Iowa." (Lower Burlington.)

Graphiocrinus spinobrachiatus Hall. Wachsmuth and Springer 1880, p. 123 (346).

The dorsal cups of this species are usually flattened, giving them a more broadly turbinate to bowl-shaped appearance than is really the case.

Holcocrinus wachsmuthi (Meek and Worthen), new combination.

Poteriocrinus (*Scaphiocrinus*) *wachsmuthi* Meek and Worthen 1861, p. 141.

"Burlington limestone, Burlington, Iowa." (Lower Burlington.)

Poteriocrinus (*Scaphiocrinus*) *wachsmuthi* Meek and Worthen. Meek and Worthen 1868, p. 488, Pl. 16, Figs. 7a, b, Text-fig.

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U. S. Geological Survey,
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SCIENTIFIC INTELLIGENCE

CHEMISTRY.

The Theory of Resonance and its Application to Organic Chemistry; by GEORGE WILLARD WHELAND. Pp. vi, 316. New York, 1944 (John Wiley and Sons, $4.50).—One of the important needs after the War will be for books which gather together and interpret the progress which has been made during the last decade or so, and which correlate it with and show it in perspective against the earlier scientific achievements. Such books will be invaluable to the student now in the Services who returns to civilian life, as well as to the teacher who has perhaps found too little time for keeping up with the "literature." Professor Wheland's book fills this need in the field of resonance theory as applied to organic chemistry.

The contents of this volume may be described through the chapter headings. (1) The theory of resonance. In this chapter there is given a "rather detailed, but non-technical and actually non-mathematical, discussion of the essential fundamental principles" (p. viii) of resonance theory, which is yet rigorous and clear. (2) The nature of valence. This chapter is a review of fundamentals and contains a particularly good section on the hydrogen bond. (3) Resonance energy. This is a discussion of methods of measuring or calculating resonance energy of molecules and includes a very interesting brief discussion of hyperconjugation. (4) Steric effects of resonance. Here is treated the effect of resonance in producing symmetry in certain molecules, radicals and ions; in producing coplanarity; and in affecting the distances between atoms in different types of bondings. (5) Resonance and dipole moments. (6) Resonance and molecular spectra. This is a discussion of some of the ways in which the concept of resonance has helped to reconcile molecular structures and observed spectra. (7) Resonance and chemical equilibrium. This very important chapter shows how resonance theory can help one to understand why various structural changes in organic molecules influence the positions of chemical equilibria (i.e., acid and base strengths, addition reactions, formation of free radicals, tautomeric equilibria) as they do, and how it helps to predict effects and choose optimum conditions for desired results. (8) Resonance and chemical reaction. A discussion of the ways in which resonance can affect the course of a chemical reaction and its rate by influencing the stabilities of reactants, activated complex and products.

It is apparent that this book covers a very broad field, as broad in fact, as organic chemistry. While the emphasis is primarily upon the aspects of the subject which the concept of resonance can clarify, yet other points of view are brought in from time to time. Thus the reader feels that though he is restricted by necessity to the careful consideration of resonance concepts yet he is not allowed to lose sight of alternative treatments. This contributes greatly to the breadth of the work.

Another important feature of the book is that it can be used as a text or a reference book since it is a synthesis of both. It is very thoroughly documented, and the author makes useful comments in the footnotes with regard to some of the references he gives. In addition, phrases and sentences such as the following: "The correct explanation of the facts is not known at present" (p. 204); ". . . the two final predictions, however, appear not to have been tested experimentally" (p. 262), illustrate a stimulating feeling of incompleteness which appears throughout the book. There is always the suggestion that better treatments are possible, that thus and so needs further investigation, so that the reader, while being made aware of what has been done, is conscious of being led to the expanding edge of knowledge in the field. This cannot help but be challenging. The Reviewer would have liked to see in this book a chapter or section devoted to the new ways of thinking which have led to the symbols of the resonance theory. This is not treated explicitly anywhere, though there is some implied feeling for this, particularly in the section on hyperconjugation.

This volume is worth the reading by every active organic chemist for even if he has kept up well with current literature yet here is a review, and an in itself interesting synthesis which is well written, clear and stimulating.

The book is well made, the type clear and remarkably free from misprints: the reviewer noticed only two. A most useful feature of the book is an appendix which is a table of interatomic distances in organic molecules.

HAROLD G. CASSIDY.

Ebulliometric Measurements; by W. SWIETOSLAWSKI. Pp. xii, 228; 64 figs. New York, 1945 (Reinhold Publishing Corp.; $4.00). —"To the memory of those who gave their lives for Poland and Warsaw." Thus this book is dedicated. It has been largely through the work of the author, now in this country, and his collaborators that the methods of ebulliometry have been advanced to their present high precision. The former book "Ebulliometry" has been rewritten and adapted to the American reader.

The wide variety of investigations which may be carried out using ebulliometric methods are easily observed from the chapter headings. The first four chapters discuss the methods and apparatus used and give a review of the type of boiling mixtures encountered. The other chapters are: Determination of the Degree of Purity of Liquids, Applications of Ebulliometers to the Study of Azeotropy, Purification of Liquid Substances and Microebulliometric Determination of Impurity Content, Microebulliometric Determination of Moisture Content, Microebulliometric Determination of Impurity Content of Solid Substances, Ebulliometric Examination of Thermal Resistivity, Microebulliometric Determination of the Amount of Vapors Adsorbed by Solid Substances, Macroebulliometric Determination of Moisture, Molecular Weight Determination of Solid Substances, Boiling and Condensation Phenomena Observed under High Pressure, Ebulliometric Measurements Under High Pressure, Determination of the Solubility of Solid Substances, Ebulliometric Method of Determination of Equilibrium Constants, and Ebulliometric Examination of Physiochemical Standards. The type of ebulliometer and the methods used for these various determinations are discussed together with the data of a typical experiment.

It is possible that with the publication of this book the methods of ebulliometry will have wide spread use in the chemical laboratories of this country.

SCOTT E. WOOD.

Fundamental Principles of Physical Chemistry; by CARL F. PRUTTON and SAMUEL H. MARON. Pp. x, 780. New York, 1944 (The Macmillan Co., $4.50).—The scope of this excellent new textbook of physical chemistry can be no more concisely summarized than by a quotation from the authors' introduction:

"The present text starts with a discussion of the behavior of gases, liquids, solids, solutions, and colloids. This discussion embraces the first eight chapters, except for Chapter II, in which certain necessary elementary principles of thermodynamics are introduced. These principles of thermodynamics are extended in Chapters IX, X, and XI, and are applied to a consideration of chemical equilibria in Chapters XII, XIII, and XIV. Beginning with Chapter XV and extending through Chapter XVIII there is given an exposition of the principles of electrochemistry, i.e., the interaction of matter and electricity. This is followed by a consideration of the rates of homogeneous reactions, Chapter XIX, and heterogeneous reactions, Chapter XX. Finally, in Chapters XXI and XXII, accounts are given of our knowledge of atomic and molecular structure, while in the last chapter the information of atomic

and molecular structure is applied to correlation of physical properties with chemical constitution."

There are many features of this text which are pleasing to this reviewer. In Chapter I there is given a rather complete elementary discussion of the kinetic theory of gases. The very brief discussions in some other texts are likely to serve best as sources of misconceptions on this important matter. Again, the early introduction and use of the thermodynamic method is to be applauded. As early as Chapter II direct use is made of general thermodynamics. Such a procedure does have a slight disadvantage. The student cannot appreciate the full meaning of a general formula at so early a stage. But if his appreciation does not grow, the student is busying himself with the wrong subject in any case.

The authors have supplemented each chapter by a list of references for further reading and by a group of problems. The references are large in number; it would seem that most of the important monographs and text-books in English bearing on physical chemistry have been mentioned. The problems are good. During the later stages of a course the instructor may want to supplement those given with others of a more detailed nature having a closer relation to the scientific and technical literature of the subject.

While errors are not numerous there are a few which might confuse the student. A peculiar interchange of symbols has occurred in the derivation of the phase rule on page 382. If the algebra had remained accurate after this interchange the conclusion drawn would be most astonishing. An erroneous statement regarding the sign of a rate expression occurs on page 610. The minus sign before dC/dt has, of course, nothing to do with the fact that the rate may decrease with time. (In the same paragraph *specie* is used as the singular of *species*.) § The typography is simple and clear and the book manufacture good.

This text should receive a warm reception by instructors in serious courses on physical chemistry, the more so now that the time appears to be near when we can drop acceleration and return to education.

HENRY C. THOMAS.

Textbook of Organic Chemistry; by E. WERTHEIM. Second Edition. Pp. xiv, 865; 118 figs., 2 plates. Philadelphia, 1945 (The Blakiston Co., $4.00).—The second edition of Wertheim's book, like the first (see AMER. JOUR. SCI. *237*, 607 (1939) follows the conventional order of presentation of topics and contains only minor changes from the former edition. The positions of several chapters in the latter part of the book have been rearranged but the content of most chapters is little changed. The review questions and charts have been expanded and two full color plates showing scale molec-

ular models have been introduced. One of the best features of the book is the inclusion of liberal references to original articles at the end of each chapter; these form a good basis for supplementary student reading. JAMES ENGLISH, JR.

MISCELLANY.

Telescopes and Accessories, by GEORGE Z. DIMITROFF and JAMES G. BAKER. Pp. v, 309; 146 figs. Philadelphia, 1945 (The Blakiston Company, $2.50).—There are relatively few books on the subject of telescopes, and for this reason this seventh volume in the series of Harvard Books on Astronomy will be a welcome addition to many library shelves. In judging its qualities it is necessary to keep in mind that the aim was to appeal to a wide audience, including the lay reader, the amateur astronomer interested in making his own telescope, as well as the professional astronomer. This made it necessary to limit the discussion of subjects such as coma, spherical aberration, the performance of multi-lens cameras, and Schmidt cameras to a descriptive treatment. While this makes good reading, it may leave the wish for an appendix with some of these matters more precisely stated. The authors have frequently used the device of introducing a rapid summary of technical details after a leisurely descriptive treatment. These changes of content are so noticeable in some chapters that the reader often wonders whether he distinguishes the contributions by the individual authors.

The subject of the optics of telescopes occupies the earlier chapters; the last two chapters deal with the mechanical features of the larger instruments, one being devoted to instruments for solar research. Amateur telescope making receives only brief treatment, but the reader interested in this subject will nevertheless find much useful information. A considerable portion of the book is occupied by chapters on photography, on instruments for measuring the intensity of light, and on astronomical spectroscopy.

DIRK BROUWER.

American Journal of Science

OCTOBER 1945

SCIENTIFIC EXPLORATIONS IN SOUTHERN UTAH.

HERBERT E. GREGORY.[1]

ABSTRACT. The salient geographic features of southern Utah were briefly described and crudely mapped in 1776 by the Dominquez-Escalante Expedition Additional information, especially for the Virgin River valley, was given by the fur traders—Jedediah Smith (1826) and William Wolfskill (1830) and before 1870 the Mormon pioneers had explored most of Utah west of the Glen Canyon in search for agricultural and grazing land and sites for settlement Scientific investigation resulting in maps, reports, descriptive of the topography, geology, plant and animal life, and mineral resources has been the work of Federal agencies beginning in 1853 in southwestern Utah, 1859 in the San Juan County and 1869 along the Colorado Canyon. It concerns chiefly the activities of exploring parties under the direction of Fremont, Macomb, Powell, Wheeler, Hayden, and the Geological Survey.

INTRODUCTION.

KNOWLEDGE of the topography, geology, and natural history of southern Utah came late, after adjacent regions had been explored—in fact, after most other parts of the United States had been represented by reconnaissance maps. By the middle of the nineteenth century northern Utah was fairly well known. Salt Lake was found by James Bridger in 1824, and during the decades 1830-1850 Green River, the Uinta Mountains, and the Wasatch Mountains were explored by trappers and prospectors, trading posts and military stations were established, and the old "Spanish Trail" through western Colorado and north central Utah was a much-used highway. For parts of this region maps and geographic descriptions had been prepared by Bonneville (1832-33), Fremont (1842-45), Stansbury (1849-50), Gunnison (1853), and King (40th Parallel Survey, 1868). Likewise, before 1860 the lands south of the Grand Canyon of the Colorado had been traversed many times by

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Spanish military and ecclesiastic officials, who left reports of their observations on scenic features, soil, climate, and especially the native inhabitants. The information recorded by Diaz (1540), Cardenas (1540), Onate (1604), Carces (1775), Fout (1777), and other priests and adventurers, while travelling back and forth from Mexico or Santa Fe to California in search of suitable sites for missions, was greatly increased by the military and geographic explorations of Emory (1847), Derby (1850), Sitgreaves (1851-52), the United States and Mexican Boundary Commission (1849-1855), Whipple (1854), Parks (1855), and Ives (1857-58). Of the early Spanish explorers only Cardenas (1540) reached the Colorado River, and only Escalante (1776) crossed it. Likewise the pioneer scientific expeditions stopped at the brink of the Grand Canyon and saw little reason for going beyond. Thus Ives remarks: (1)*

> "Ours has been the first and will doubtless be the last party of whites to visit this profitless locality. It seems intended by nature that the Colorado River, along the greater part of its lonely and majestic way, shall be forever unvisited and undisturbed."

For southern Utah the earliest geographic descriptions are by Escalante (1776) and the two energetic fur traders, Jedediah S. Smith (1826) and William Wolfskill (1830). But for nearly a century the famous "diary" of Escalante remained buried in the archives of Spain and Mexico. Smith's original account seems to have lain unnoticed in the government files until interpreted by Sullivan, (2) and the observations of Wolfskill have but recently been made accessible—chiefly by Camp who reproduces the record of Yount, a member of the Wolfskill expedition. (2a) For the 20 years that followed the establishment by Wolfskill of a feasible route to California, the exploratory record is barren; during this period no available manuscript or printed paper reveals knowledge of any part of southern Utah except along the Old Spanish Trail through Iron and Washington Counties. In fact southern Utah was practically unknown until systematic scouting by the Church of Latter Day Saints introduced the epoch of colonization.

Between 1850 and 1870 officials of the Church had become familiar with the water supply, the soil, and farm lands in Ash, Virgin, Parunuweap, Kanab, Johnson, Sevier, and Paria Val-

* Numbers in parentheses indicate the references at the end of the paper.

leys, and along the base of the Hurricane Cliffs; with the timber and grazing resources on the Markagunt and Kaibab Plateaus and Pine Valley Mountains; and with the grass lands on the Kolob Terrace and south of the Vermilion Cliffs. Before 1880 the potential agricultural resources of the Upper Sevier, the Escalante, and the San Juan Valleys were known. For the purpose intended—primarily the selection of sites for settlement—these Mormon explorations were remarkably complete. On them were based the developments that have given southern Utah its unique position among regions dependent on irrigation farming and stock raising. However, these surveys were concerned almost wholly with matters that immediately affected the welfare of the adventurous pioneers and therefore in a geographic sense lacked many desirable features. They are represented in the literature by brief newspaper items that say almost nothing of the topography and drainage and are unaccompanied by maps. Notable exceptions are the records of the expedition led by Parley P. Pratt (1851) into Ash Creek, Santa Clara, and Virgin Valleys; the report of the master scout John D. Lee and his associates (1852) that made known the geographic features of Markagunt Plateau, the upper Parunuweap Valley, and the Vermilion Cliffs; and the account of Capt. James Andrus (1866) of his journey up Paria Valley and into Potato Valley (Escalante Valley); and the several reports of Jacob Hamblin that concern his search for feasible crossings of the Colorado canyons, finally resulting in the establishment of Lees Ferry (1870). Thus it has come about that the scientific knowledge of southern Utah—mapping and the description of the topography, geology, plant and animal life, mineral resources—is recorded by Federal surveys, beginning 1853 in southwestern Utah, in 1869 along the Colorado canyons, and in 1859 in the San Juan country. It concerns chiefly the work of parties under the direction of Fremont, Macomb, Hayden, Wheeler, and Powell.

It seems worthy of note that the first systematic records of the geography and geology of the Colorado plateaus were made by the United States Army during the course of military surveys and the search for feasible railroad routes from the Missouri River to the Pacific. Recognizing the Colorado canyons as impassable barriers, most of the Army expeditions passed through central Arizona or northern Utah. Only those led by Capt John C. Fremont, Captain J. N. Macomb, and Lt. George

M. Wheeler conducted operations in southern Utah and in Arizona north of Grand Canyon.

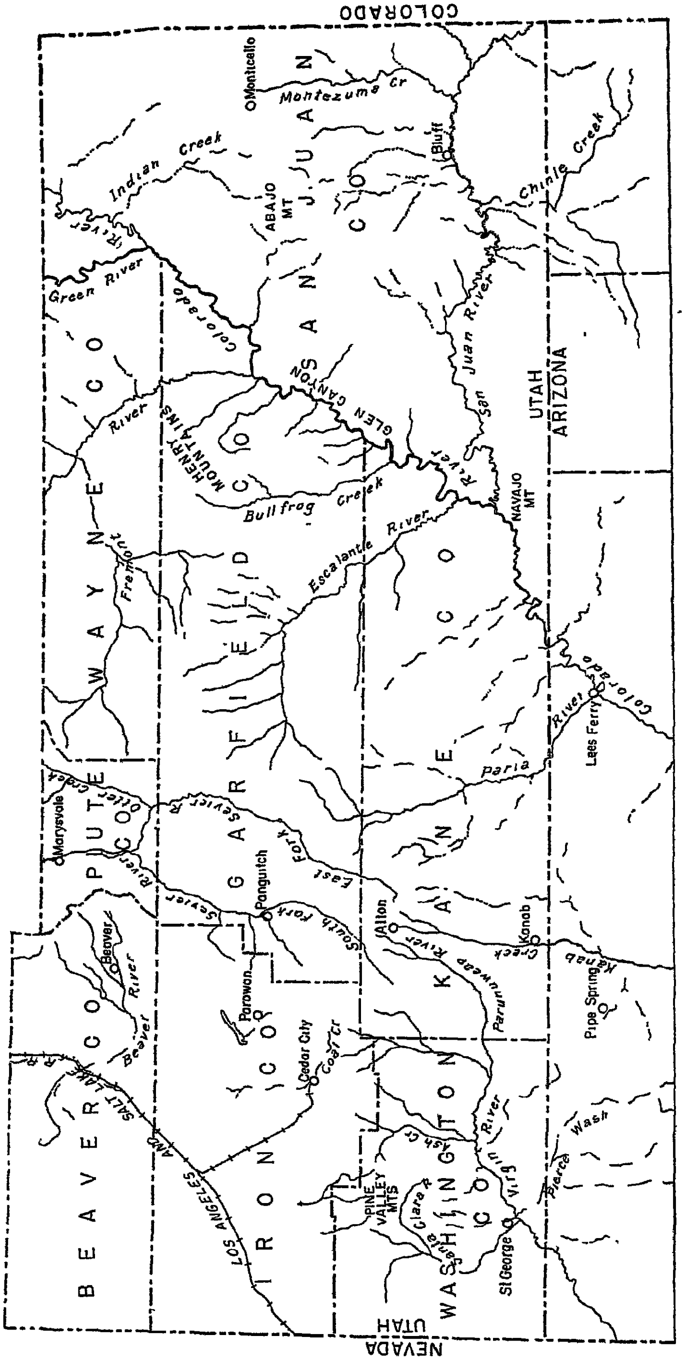
EXPLORATIONS WEST OF GLEN CANYON

ENTRADA OF ESCALANTE.

The diary of Escalante (1776) and the accompanying map outline for the first time the salient topographic features of southern Utah and northern Arizona. (3) Most of the descriptions in the text, though brief and written in unscientific language, apply fairly well to the landscape of eastern Iron and Washington Counties and of Kane and San Juan Counties as analyzed by more recent surveys, and on the crudely drawn map the major mountain ranges, the rivers, and the cliffs are shown in their approximate positions. Features recognizable include the Hurricane Cliffs south of Cedar City, Ash Creek Valley (N. S. Pilar, Rio de Nuestra Senora de Zaragosa), Pine Valley Mountains, Toquerville (S. Ugolina), Virgin River (Rio de les Piramides Sulfurio), Fort Pierce Wash (?) (Arroyo de Tarai), Uinkaret Mountains, northern Uinkaret Plateau (Este la Mesa y sin Aqua), Pipe Springs (Jubuin Carin S. Samuel), Kanab and Johnson Valleys (Sta. Barbara), Navajo Wells, the Kaibab Plateau, lower House Rock Valley (S. Bartolome), Paria River (Rio Santa Teresa), Sentinel Rock Creek (Rio San Diego), and the Indian ford across the Colorado (El Rio Grande Colorado) now known as the Crossing of the Fathers. On the map the rugged lands in the Zion Park region (Sierra Blanca) and the Kaiparowits Plateau are represented and also the Table Cliffs (Sierra de los Suacaros) as seen from a distance of 40 miles.

FREMONT EXPEDITIONS.

On his second expedition to California, Capt. John C. Fremont spent two months (August and September, 1843) in northern Utah. His return route followed substantially the "Old Spanish Trail" along Virgin River, Santa Clara River, and the base of the Wasatch to Timpanogos Lake, renamed by him Utah Lake. In passing over the Beaver Dam Mountains, and up the Santa Clara River and Magotsu Wash to Las Vegas de Santa Clara [Mountain Meadows] in the present Washington County (May 10-16, 1844), Fremont noted the marked change in vegetation, topography, and geologic structure: the mountains "here began to be wooded with cedar and pine and clusters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HENRY MOUNTAINS
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Panguitch
South Fork
Alton
Kanab
Kanab Creek
Parunuweap River
Pipe Spring
Beaver
Beaver River
Parowan
Cedar City
Coal Cr
SALT LAKE AND LOS ANGELES R.R.
PINE VALLEY MTS
Ash Cr
Virgin River
Santa Clara R
St George
Pierce Wash

of trees gave shelter to birds—a new and welcome sight—which could not have lived in the desert we had passed. . . . The stream [Santa Clara River] is prettily wooded with sweet cottonwood trees . . . a different species from any in Michaux's Sylva . . . the snowy mountains on our right [Pine Valley Mountains] showed out handsomely—high and rugged with precipices, and covered with snow for about two thousand feet from their summits down." In crossing the low divide at the head of Mountain Meadows, Fremont realized that he had left the Colorado drainage system and entered a region of interior drainage, the southern edge of the great region that includes Sevier Lake, Salt Lake, and innumerable salinas, playas, and rugged mountain masses between the Wasatch and the Sierra Nevada. "We considered ourselves as crossing the rim of a basin." For this vast area he adopted the term "Great Basin" which has become fixed in geographic literature.

On his second expedition (1843-44), also on his third expedition (1845-47), Fremont followed few trails not previously traversed by Santa Fe traders. His chief part in "breaking the wilderness" was observation and painstaking record and the preparation of comprehensive reports which aroused the interest of government officials, of scientists, and laymen. On his fifth expedition (winter of 1853-1854) undertaken to locate "a central route" for a railroad to the Pacific, Fremont traversed new country in eastern Utah and in southern Utah visited the stockaded villages of Parowan and Cedar City—the first permanent settlements (founded in 1851). His route crossed Green River near the mouth of the San Rafael—south of previously known crossings—followed the San Rafael River for a distance, then the front of San Rafael Swell to an unknown river (Fremont River) and up the river through Rabbit Valley to the Awapa Plateau south of Fish Lake. The route then led down Otter Creek (Grass Valley), down the East Fork of Sevier River, and up the Sevier to Circle Valley, and across the southern Tushar plateau to the Salt Lake-California road. The brief account of this traverse by Fremont (3a) supplemented by Carvalho, (4) artist to the expedition, and by Bigelow (5) is a story of endurance and resource.

"After we crossed the Green River the whole party was on foot." The horses were used for food. Before reaching the Sevier "we lived on horse meat fifty days." To release the pack mules for riding, all "superfluous baggage was cached—

pack saddles, bales of cloth, travelling bags, scientific instruments, gun powder, and lead; nothing was to be retained but the actual clothing necessary to protect us from the inclemency of the weather." The last stages of the journey, three days of wandering through the mountains northwest of Panguitch, was particularly hazardous. Over rough ledges through snow "up to the bellies of the animals" with "temperatures below zero" a trail was broken. "None of us had shoes; some of the men had raw hide strapped round their feet, while others were half covered with worn out stockings and moccasins. We were reduced to rations of dried horse meat" and "forty-eight hours without food of any kind." On February 7 the party entered a "defile of the mountains" (now known as Fremont Pass) and, following "the dry bed of a stream," found ruts of wagon wheels on the plain below (Buckhorn Flat). The next day the stragglers reached the settlement of Parowan, but in desperate plight. "The whole of my party were all exhausted and broken up." Several of the men had to be carried. One died on the trail. "At Parowan the Mormons treated us very kindly; every family took in some of the men, putting them into clean, comfortable beds, and kind-faced women gave them reviving food and pitying words." In a letter to his sister Fremont wrote, "The Mormons saved me and mine from death by starvation."

In an account of this expedition the Deseret News (July 5, 1854) reports: "the two Spaniards which Fremont sent back for some cached articles had been killed. * * * Soon after the Spaniards took out the articles, some Indians rushed upon them, killed them, and took the property, scattering the contents of the mail sacks and destroying the surveying instruments." On February 21, 1854, Fremont continued his journey to California with such members of his expedition as were able to travel, the sick remained at Parowan for several months or were taken by wagon to Salt Lake City for special treatment.

The widely distributed reports of the Fremont expeditions are outstanding contributions to western history. They had no small influence in the controversies that led to the acquisition by the United States of northern Mexico—lands in the present Arizona, Utah, Nevada, and California, and they are known to have influenced the Mormons in their choice of a field for colonization. Unlike the trappers and traders who left scant record of their travels, Fremont mapped his route, made astronomical observations for latitude and longitude, collected

plants and geological specimens, (studied by John Torrey and James Hall), and recorded information regarding forage, timber, water supplies, and the native inhabitants. His account is a straightforward geographical narrative. "The report like the maps which illustrate it will be strictly confined to what was seen, and to what is necessary to show the face and character of the country, and to add something to science while fulfilling the instructions of the government which chiefly contemplated a military topographic survey." (6)

WHEELER SURVEY.

The Wheeler Survey (officially the U. S. Geographic Surveys West of the One Hundredth Meridian in charge of Capt. Geo. M. Wheeler), was the most extensive and elaborate scientific investigation ever undertaken by the Engineer Corps of the United States Army. Though not organized on a regional scale until 1872, the Survey was in reality a continuation of the exploratory expeditions in 1869 and 1871. As described by Wheeler (7) the survey authorized by Congress (June 10, 1872)

> "was a plan substantially for a complete, connected, continuous, detailed topographic survey (with associated natural history observations) of the territory of the United States west of the one hundredth meridian with primarily a resultant topographic map, scale 1 inch to 8 miles, to be in the main an aid to military administration and operations, to occupy about 15 years and to cost in all not exceeding $2,500,000 . . . It was to have been the first great general survey of the country during its initial stages of settlement."

This ambitious project for detailed mapping, evaluation of the natural resources, and description of the geology, botany, and zoology within an area of 1,443,360 square miles was not completed, but before field work ended (1879) and the compilation of maps and reports was discontinued (1884) the survey had made an invaluable contribution. The 50 published sheets of the Wheeler topographic atlas cover 326,891 square miles and manuscript sheets an additional 31,174 square miles—areas that embrace 66 per cent of New Mexico, 54 per cent of Arizona, 32 per cent of Colorado, 46 per cent of Utah, 60 per cent of Nevada, 41 per cent of California, and considerable areas in Idaho and Oregon. The larger illustrated volumes on geology, paleontology, zoology, botany, and archeology are introduc-

tions to fields of great scientific interest, and the 9 annual progress reports, 18 special reports, and the final comprehensive report (1886) give information about mineral deposits, timber, arable land, grazing areas, water supply, routes of travel, and native races that must have been welcomed by the host of immigrants who sought homes west of the Rockies. The reports and recommendations served also as guides in legislation.

In southern Utah studies were made by the Wheeler Survey in 1871 and 1872. In 1871 the lower Virgin River Valley was mapped; in 1872 the Survey staff of 25 scientists and engineers, 6 officers, 50 privates, 2 guides, and a score of packers, herders, and laborers mapped the region northward from the Grand Canyon well onto the High Plateaus and eastward from Nevada to the Crossing of the Fathers in Glen Canyon. Regarding his pioneer traverse of the Markagunt Plateau Wheeler (8) writes:

"Skirting the rim of the plateau a break in the wall is finally found, and the train taken down into a box canyon along a descent having an angle of fully 55° at the head of La Verken Creek. The summit of the southern rim (of the Markagunt Plateau), at an altitude of over 10,000 feet, affords one of the finest panoramic views then witnessed (1872)—the Virgin River lying at our feet, the Colorado Canyon in the distance, plateaus, canyons, and mountains to the east, mountains high and frowning to the north, and the mountains and desert to the west and southwest, the ranges bordering the Colorado, especially the Virgin. Below us lay the brown and black bristling ridges of the eroded mesas that for grandure of beauty and desolation of appearance far surpass all that words can express. Clambering along the cliff, and while securing a large haul of fossils, the crisp edge of coal crops was noticed, and prospecting which a 12-foot vein of dense bituminous coal, having both above and below a bed of shale 15 to 18 inches thick, was found, with petrified wood strewn in many directions Fossils were found in sandstone. . . . Usually volcanic material appears on the surface of the Colob [Kolob Terrace] with occasional limestone, sandstone, and shale. There is a fine growth of grass and groves of quaking aspen."

In Long Valley (Parunuweap Valley) Wheeler followed a primitive wagon road through Glendale and Mount Carmel and on down the Parunuweap Canyon to "6-mile turn," then finding that further progress downstream was impossible for horses he ascended the canyon wall, crossed the rough, and Moccasin

Terrace and finally reached Shunes Mountain below which the river was again in sight. In desperate need of water his party scrambled down the canyon wall to the little settlement of Shunesburg 2,000 feet below. Wheeler says:

"Our coming created a sensation, as no party, except on foot, had ever been known to pass this route, unless it were an adventurous mail-rider with a trusty-led mule, in case of great emergency. Nothing short of considerable blasting could render the trail passable even for pack animals."

A drawing of the "Wriggle Trail" at Shunesburg (reproduced as plate 55 in the Wheeler report) is the first known illustration of the great rock walls of Navajo sandstone that dominate the landscape of southwestern Utah.

The geologic work of the Wheeler Survey was done chiefly by G. K. Gilbert and Edwin E. Howell. Of his three years service with the Wheeler Survey (1871-1873), Gilbert spent the first in Nevada and western Arizona, the second in southwestern Utah and northwestern Arizona, and the third in New Mexico and eastern Arizona. In Utah (1872) he spent some days on the south rim of Markagunt Plateau, traversed for the first time the Virgin River from its source in the Pink Cliffs below Navajo Lake, through Zion Canyon, Timpoweap Canyon, and on to St. George; followed the Vermilion Cliffs through Cane Beds, Pipe Springs, Kanab, and eastward to the Paria; and made special studies of the Kaibab fold, of the Sevier fault, and the Hurricane fault. In his field notebook (1872) Gilbert makes some interesting comments.

"At Zion (Springdale) we furnished our own blankets and slept on the floor. At Rockville the same except we were furnished pillows. At Mt. Carmel we were given extra blankets and the lee-side of a corn stack. At Toquerville I slept in a wagon box with the boy; at Workmans Ranch [Goulds Ranch] on the ground with the boy again At Kanab in a bed on a bedstead alone, at Allendale (Glendale ?) ditto with the boy.

"The north fork [of Virgin River] has opened a valley in the Cretaceous, but too narrow for cultivation. From the foot of this valley to the hamlet of Little Zion, the stream traverses, in the most wonderful defile it has been my fortune to behold, the massive sandstone of the Gray and Vermilion Cliffs, here combined in a single undistinguishable body, certainly not less than 2,000 feet in depth. At the head of 'The Narrows' the top of this bed is at the water's edge; and, as the strata rise, and the stream descends southward,

the height of the canyon walls gradually increases, until it includes the entire mass of sandstone (in Zion National Park). At the water's edge the walls are perpendicular, but in the deeper parts they open out toward the top. For a number of miles the bottom of the cleft averages 30 feet in width, contracting frequently to 20, and in many places is entirely occupied by the stream, even at its low stage."

Howell, who served two years with the Wheeler Survey (1872, 1873) and one (1874) with the Powell Survey, likewise, "traversed portions of the Sierra region of western Utah and adjoining Nevada" and the lower Virgin Valley. His reconnaissance included geographic and geologic studies of the Aquarius and Paunsaugunt plateaus, of the region about the head of the Paria River and of the cliffs and canyons in the vicinity of Toquerville.

The published reports of the Wheeler Survey are highly important contributions to the geography and geology of southern Utah. The hachure maps depict the landscape in remark able detail and the accompanying text discusses not only physical geography but also human geography to an extent unusual for scientific reports. The geologic maps and the famous "Volume 3—Geology" prepared by Gilbert and Howell represent pioneer studies; they were treated by later surveys as source material. The volumes of botany, zoology, and archeology are standard reference works.

POWELL SURVEY.

The Spanish in their search for converts and trade and the Americans in their search for beaver hides became acquainted with the Green River and its tributaries, but saw no reason to explore the "inaccessible and worthless country" below the mouth of Price River. Likewise the military expeditions in search for routes for transcontinental railways avoided the Green River below Gunnison Crossing (village of Green River, Utah). They doubtless recalled the remarks of Capt. Macomb (9) (1859) on the country at the junction of the Green and the Grand (Colorado). "I cannot conceive of a more worthless and impracticable region." The army engineers met fewer obstacles in constructing roads through mountain ranges than in crossing the relatively flat but intricately dissected plateaus bordering the Colorado River. It remained for Major Powell

to explode the myths of "sucking whirlpools," "underground passages," and "plunging, roaring waterfalls" in the "mysterious" Colorado River by safely navigating its canyons to their mouth.

Powell first came to the plateau country in 1867 as a free-lance collector of museum specimens in northwestern Colorado and adjoining parts of Utah. He quickly became "fascinated" with this little-explored region of "canyons and brightly colored rocks" and was eager to visit the even less known lands farther south. During his second field season (1868), while collecting along the Green River canyons, his nebulous wishes seem to have taken definite form in the audacious plan of descending the Green and the Colorado by boat. The opportunity came the following year. Thus began the series of expeditions that drew attention to the canyons and plateaus that make of southern Utah a region of scenic grandeur. In the words of Powell (10): "begun originally as an exploration the work has finally developed into a survey embracing the geography, geology, ethnography, and natural history of the country. . . ."

The first traverse of the Colorado River by Powell (1869) ranks high among feats of daring. As Gilbert remarks (11): "The undertaking was . . . of phenomenal boldness and its successful accomplishment a dramatic triumph. It produced a strong impression on the public mind and gave Powell a national reputation which was afterwards of great service."

Obviously Powell's pioneer traverse was planned for exploration rather than for research—to "navigate the Green and the Colorado in the shortest practicable time." The essential tasks of procuring supplies and propelling boats through 1,050 miles of unknown canyons at the rate of about 20 miles a day left little time for scientific observations beyond the recording of approximate distances and directions. Furthermore it appears that the exploring party included no professional scientists, no men experienced in designing and operating boats and, with the exception of its leader, no one familiar with the conditions that control field work. As viewed by such "river men" as Bert Loper and Norman Nevills who nowadays conduct tourists in safety and with reasonable comfort through Cataract, Glen, Marble, and Grand Canyons, the difficulties encountered by Powell are plain evidence of unsuitable equipment and inexperienced personnel.

In evaluating the work of the 1869 expedition it seems nat-

ural to find Powell "not satisfied with the results obtained" and "determined to continue the explorations of the canyon of the Colorado . . . to once more attempt to pass through the canyon in boats, devoting two or three years to the trip." In preparation for this proposed second voyage, Powell returned to Utah in 1870 and selected places where supplies might be brought to the Colorado River by pack train. In September, accompanied by Jacob Hamblin, he visited the Shiwits Indians on the Uinkaret Plateau to investigate the death of three members of his expedition of 1869 who had left the river party near Toroweap Canyon. On this traverse Powell took occasion to descend the old Piute trail from the Toroweap (Tuweap) Valley to the Colorado and to examine the most prominent peaks of the Uinkaret volcanic field. Two of these peaks he named Mount Trumbull and Mount Logan (senators from his home state, Illinois) and the third Mount Emma (Emma Dean, Powell's wife). On the Toroweap road south of Pipe Springs, Powell first noted the glorious banded wall along the south face of Moccasin Terrace.

> Starting, we leave behind a long line of cliffs, many hundred feet high, composed of orange and vermilion sandstones. I have named them Vermilion Cliffs. When we are out a few miles, I look back, and see the morning sun shining in splendor on their painted faces; the salient angles are on fire, and the retreating angles are buried in shade, and I gaze on them until my vision dreams, and the cliffs appear a long bank of purple clouds, piled from the horizon high into the heavens.

In 1871 on his second traverse of the Green and the Colorado, Powell was in charge of the boat party from Green River, Wyoming, to the mouth of the Duchesne (May 22-July 14) and from Green River, Utah, as far as the Crossing of the Fathers (September 2-October 10). Here he left the river and returned to Washington by way of Paria, Kanab, and Salt Lake City.

Powell's most active season in southern Utah was in 1872 when he directed the river party on its cruise from Lees Ferry to the mouth of the Kanab Creek (August 17-September 7), traversed Kanab and Virgin Valleys, and examined the Vermilion Cliffs from Smithsonian Butte eastward through Short Creek, Cane Beds, Pipe Springs, and Kanab. From a camp in a "beautiful meadow at the head of the Kanab," Powell ascended the "wall of the Pink Cliffs" (rim of the Paunsaugunt Plateau

at Alton) and explored the broken country "where the Rio Virgin and the Sevier rivers are dovetailed together" (Gravel Pass). From the pass he conducted the pack train along the old road down the Parunuweap Valley (Long Valley), to Mount Carmel and then on foot followed the Parunuweap Canyon to the Mormon settlement of Shunesburg. This first traverse of the formidable gorge, one of the few that ever have been made, he described in detail. (12) After spending a night at the Shunesburg Ranch, Powell and companions followed the Virgin River northward into the present Zion Canyon.

"The Indians call the cañon *Mu-koon'-tu-weap,* Straight Cañon. Entering this, we have to wade up stream; often the water fills the entire channel, and, although we travel many miles, we find no flood-plain, talus, or broken piles of rock at the foot of the cliff. The walls have smooth, plain faces, are everywhere very regular and vertical for a thousand feet or more, where they seem to break back in shelving slopes to higher altitudes, and everywhere, as we go along, we find springs bursting out at the foot of the walls, and, passing these, the river above becomes steadily smaller; the great body of water, which runs below, bursts out from beneath this great bed of red sandstone; as we go up the cañon, it comes to be but a creek, and then a brook. On the western wall of the cañon stand some buttes, towers, and high pinnacled rocks. Going up the cañon, we gain glimpses of them, here and there . . . These tower rocks are known as the "Temples of the Virgin."

Powell's account of his explorations (13) is in several respects unusual. As a geographic sketch of southern Utah its brevity is exasperating. Of its 203 pages, only 13 are descriptive of overland trips, and of the space allotted to the river traverses, about half is given to the Green River. Fortunately his meager reports are supplemented by the diaries of Alvin H. Thompson, (14) Frederick C. Dellenbaugh (15) and Stephen Jones, (16) who were members of river parties and the land parties during 1871 and 1872, and further supplemented by the records of the Mormon Church and by diaries of farmers and stock men from whom the explorers obtained supplies and information. At the time of Powell's visit, Glendale, Mount Carmel, and Rockville were thriving settlements and fields were cultivated on the floor of Zion Canyon.

In comparing the available documents relating to the Powell survey some inconsistencies appear. For example, the tra-

verses of the Green and the Colorado are described by Powell as of 1869; no mention is made of the second traverse (1871-1872) during which nearly all the scientific records were made. Likewise the land traverses of 1871 and 1872 are listed as 1870 The traverse of Parunuweap Canyon is dated by Powell as September 10-11, 1870; by Dellenbaugh as September, 1872; and by Jones, who accompanied Powell, as September 10-11, 1872.

The geographic maps of the Powell surveys are the work of A. H. Thompson and his associates, particularly F. S. Dellenbaugh, J. H. Renshawe, Stephen Jones, and J. K. Hillers. After mapping the Green and the Colorado to the mouth of the Paria (May 22-October 26, 1871), Thompson established field headquarters at Kanab and during the next six years completed a topographic survey of Arizona north of the Grand Canyon and of southern and north central Utah. The resulting reconnaissance map, issued in sections, is the first made for a considerable part of Utah and is still in use. It is the base on which are recorded the geologic observations of Powell, Dutton, Howell, and Gilbert, and of most later students of Utah geology, botany, and zoology. In making this map Thompson must have become familiar not only with the topographic relief but also with the areal extent of lava flows and stratigraphic units, with suitable camp sites, and sources of supply. Of particular value was Thompson's pioneer traverse of a route from Kanab to the mouth of Trachyte Creek (May 29-July 7, 1872) which resulted in differentiating the drainage of the Paria, the Escalante, and the Dirty Devil rivers and sketching the features of the Aquarius Plateau, the Waterpocket fold, and the Henry Mountains.

During the first four years (1869-1873) of the Powell Survey geological investigations were almost incidental. Except in the Uinta Mountains Powell himself gave little attention to geologic details. His contribution to geologic knowledge was his epochal analysis of the processes and results of land sculpture, gained from a regional reconnaissance of southern Utah. His reports are rich in generalization.

The geological work of the Powell survey assumed prominence with the appointment of E. E. Howell in 1874, and of C. E. Dutton and G. K. Gilbert in 1875. Dutton (17) gave chief attention during three field seasons to the structure and igneous history of the High Plateaus. He outlined the "District of the

EXPLORATIONS EAST OF GLEN CANYON.

ENTRADA OF ESCALANTE.

The first known reference to the geographic features of Utah east of Glen Canyon appear in the diary of Escalante (1776) and on the map prepared by Miera y Pacheco (1777 or 1778). Though his outbound route from Santa Fe to the crossing of the Green River at Jensen was in western Colorado except for a short distance along the Dolores River and the Gunnison, Escalante seems to have had considerable knowledge of the region that includes the present San Juan country. He doubtless was familiar with the reports of Fray Alonzo de Posada and Don Juan Maria de Rivera, who previously (1761) had traversed an approximately parallel and less difficult route that entered Utah near Ucola and led along the west base of the La Sal Mountains to Moab. Among Escalante's guides was Muniz, a member of the Rivera expedition who may have passed on from Rivera some of the names on the map. Rio de Nabajoo, Sierra Abajo, Sierra de La Sal, Los Cajone (Navajo Mountain ?) El Cerro Prieto (Agathla Needle) R. de N. S. de los Dolores (Dolores) and R. de los Saguaganos (Colorado below the mouth of the Dolores). Written on the map are some interesting comments, which in substance are translated as follows: The Western Sea shown on some charts as occupying the region that includes Colorado and Utah as 500 leagues (1,315 miles) wide, is firm land and thickly populated by various tribes. The mountain range at the head of Rio de S. Rafael (Colorado) is the back bone of the North American continent. Rivers on its east side enter Hudson Bay or perhaps the Gulf of Mexico; those on its west side flow to a sea at the south. Rio Colorado below the mouth of the San Juan tumbles down deep canyons between closely spaced, bare walls of colored rock.

MACOMB SURVEY.

In 1859 an expedition in charge of Capt. J. N. Macomb, Topographic Engineers, U.S.A., crossed Sage Plain on the west side of "Sierra de la Plata" and descended "Canon Colorado" (Indian Creek) to near its mouth. The homeward route was along the east base of the Abajo Mountains, down "Rio de la Abajo" (Recapture Creek) and up the San Juan to Canyon Largo in New Mexico. The descriptions given by Macomb (19) and by J. S. Newberry, geologist of the expedition. sup-

plemented by maps and colored reproduction of sketches made in the field, portray for the first time the outstanding geographic features of eastern San Juan County, both north and south of the San Juan River. The scale of the map (12 miles = 1 inch) permitted the delineation of the major drainage lines and the prominent mesas and mountains. Of his traverse northwest of Sage Plain Macomb writes:

"At the 'Ojo Verde' the Spanish trail strikes off more northwardly, to seek a practicable crossing of Grand and Green Rivers. We left the trail here, and, leaving the main body of our party encamped at the spring, with a small party of nine, went to the westward some thirty miles, under the guidance of an Indian, who had joined us many days previously, on our route to look for the junction of the Grand and Green Rivers. This part of our journey was very rough and dangerous, from the precipitous nature of the route, winding down the sides of deep and grand cañons, and it is fortunate that no attempt was made to bring forward our packtrain, as we must have lost many mules by it, and, moreover, there was not sufficient pasture for the few animals that we had with us. I cannot conceive of a more worthless and impracticable region than the one we now found ourselves in. I doubt not there are repetitions and varieties of it for hundreds of miles down the cañon of the Great Colorado, for I have heard of but one crossing of that river above the vicinity of the Mojave villages, and I have reason to doubt if that one (El Vado of los Padres) is practicable, except with the utmost care, even for a pack mule.

Looking southward across the San Juan River Macomb saw:

"Many castle-like buttes and slender towers, none of which can be less than 1,000 feet in height, their sides absolutely perpendicular, their forms wonderful imitations of the structures of human art. Illuminated by the setting sun, the outlines of these singular objects came out sharp and distinct, with such exact similitude of art, and contrast with nature as usually displayed, that we could hardly resist the conviction that we beheld the walls and towers of some Cyclopean city hitherto undiscovered in this far-off region. Within the great area inclosed by the grander features I have enumerated, the country is set with numberless buttes and isolated mesas, which give to the scene in a high degree the peculiar character I have so often referred to as exhibited by the eroded districts of the great central plateau. Here and there we caught glimpses of the vivid green of the wooded bottom-lands of the river, generally concealed by the intermediate and overhanging cliffs."

Except for the Sage Plain, "gloomy barrens covered chiefly with Artemesiae," the place names recorded by Macomb seem to be those applied by the Mexicans who travelled the "Old Spanish Trail" across San Juan and Grand Counties: Sierra Abajo (the Lower Mountains; Blue Mountains); Orejas del Osa (Bear's Ears; Elk Ridge); Sierra La Sal; Sierra Panoche (Navajo Mountain); Lana Negra (Skeleton Mesa); Agathla Needle; and Calabasa Mountains (the towers in Monument Valley).

HAYDEN SURVEY.

In southern Utah east of Glen Canyon the geographic and geologic information recorded by the expedition in charge of Captain Macomb was greatly increased by the "Survey of the Territories" in charge of F. V. Hayden, United States Geologist, who extended his investigations of Colorado and Wyoming westward into Utah—approximately to the longitude of Thompson, Moab, and Bluff. (20) As outlined by the Secretary of the Interior, Carl Schurz, in a letter to Hayden

"the ultimate design to be accomplished by these surveys is the preparation of suitable maps of the country surveyed, for the use of the government and of the nation, which will afford full information concerning the agricultural and mineral resources and of other important characteristics of the unexplored regions of the Territorial domain . . you will make such scientific observations touching the geology, geography, mineralogy, and meteorology of the country surveyed by you as may be necessary for the preparation of such maps. In addition thereto you will obtain the necessary information for the preparation of charts upon which shall be indicated the areas of grass, timber and mineral lands and such other portions of the country surveyed as may be susceptible of cultivation by irrigations and will ascertain and report upon the best methods of accomplishing this result."

In accordance with the instructions issued by the Secretary of the Interior, Hayden prepared a topographic map (scale: 1 inch=4 miles) contour interval 200 feet, a geologic map, and a map showing types of vegetation for eastern Grand and San Juan counties (1875-1876). The maps retain the names of Sierra Abajo and Sage Plain as used by the Macomb Survey and for the first time apply the terms McElmo, Montezuma, Recapture, Epsom Creek, and McCombs Creek to tributaries of the San Juan River. The mesas and towers south of the San

Juan were referred to as Monumental Valley. Two contributions of the Hayden Survey are of special interest: the first pictorial illustrations of the Sierra Abajo (Blue Mountain) region by W. H. Holmes and the first recorded description and sketches of the remarkable Pueblo ruins in San Juan, Montezuma, and McElmo Canyons, and along "De Chelly" (Chinle) Creek by W. H. Jackson.

MORE RECENT SURVEYS.

Following the pioneer studies of the Macomb and Hayden surveys and after the San Juan Valley had been colonized by the Mormons (1880), the salient topographic features of San Juan and adjoining counties were recorded on a reconnaissance topographic map by P. Holman of the U. S. Geological Survey (Abajo and Henry Mountain quadrangles, 1884). On these maps and their revised editions the new names applied are Cottonwood Wash (Macomb's Creek of Hayden), Butler Wash (Epsom Creek of Jackson), Gothic Creek, Elk Ridge, (Bear's Ear Plateau of Holmes), and Clay Hill Divide.

The first traverse of the San Juan Canyons below Goodridge (Mexican Hat) appears to have been by E. L. Goodridge in 1882. Later traverses were made by prospectors during the "Bluff gold excitement" in 1892, by Bert Loper in 1893 and 1894, and by Walter E. Mendenhall in 1894 and 1895. The canyons were examined in detail by Miser and his associates in 1921. (21) Also in 1921, a half century after Powell had traced its course, the Colorado River was accurately mapped. (22)

For many years after their publication the maps and memoirs of the Wheeler, Powell, and Hayden surveys constituted the essential scientific literature of southern Utah and adjacent parts of Arizona and Colorado. Reconnaissance studies of more recent date concern the areas not covered by the pioneer surveys—particularly the regions adjacent to Glen Canyon. (23) Since 1900 several reports and maps that describe geographic, geological, and economic features of Iron, Garfield, Washington, Kane, and San Juan Counties have been published. They are listed by Stringham. (24)

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A DESEADO HEGETOTHERE FROM PATAGONIA.[1]

GEORGE GAYLORD SIMPSON.

ABSTRACT. *Propachyrucos ameghinorum*, new species, is diagnosed and briefly described from a hitherto unrecorded Deseado (early Oligocene ?) deposit near Lat. 44-1/2° south, Long. 68-1/3° west, in central Chubut, Argentina. The type is a nearly complete skeleton, the oldest and one of the most perfect of known hegetothere skeletons. The mounted skeleton and a plastic restoration are figured.

Introduction.

IN 1933-1934 the Second Scarritt Patagonian Expedition of The American Museum of Natural History found several rich Eogene faunules of unusual character in a hitherto scientifically unexplored region of central Chubut, in Argentine Patagonia. Monographic description of these has been unavoidably delayed but is in progress. In the meantime the present note is published in order to make known one of the most important specimens and to provide a name to be used in connection with exhibition and with distribution of copies of a plastic restoration.

This specimen is the virtually complete skeleton of a small hegetothere, representing a new species assignable, with sufficient probability, to the genus *Propachyrucos* Ameghino, 1897. As far as I know, this is the first hegetothere skeleton to be mounted, although several paper reconstructions have been published. Sinclair (1909) gave such a reconstruction of *Pachyrukhos*, from the Santa Cruz, a composite based on materials in The American Museum of Natural History. Loomis (1914) gave a paper reconstruction of *Prosotherium*, a Deseado form contemporaneous with *Propachyrucos*, but the specimen involved is very incomplete and the reconstruction correspondingly hypothetical. The best single hegetothere skeleton hitherto described belongs to a Chapadmalal species of *Paedotherium*, the last survivor among the hegetotheres. Kraglievich (1926) published a paper reconstruction of this skeleton.

The present specimen is also unusual in view of the great

[1] Contributions of the Scarritt Expeditions, No. 34.

rarity of adequate pre-Miocene mammal skeletons from South America. Besides *Prosotherium,* mentioned above, Loomis (1914) gave paper reconstructions of *Protheosodon* and *Rhynchippus* from the Deseado, but both were based on inadequate materials and there is some reason to suspect that the *Protheosodon* mandible is not of the same genus, or perhaps family, as the hind legs associated with it in the restoration. Several complete skeletons of *Scarrittia,* also a Deseado form, were found by us a few kilometers from the specimen described in the present paper and two of these have been prepared in the death pose, without reconstruction or mounting (see Simpson, 1935). The present specimen is thus the first mounted skeleton from the Deseado. Skeletal remains from pre-Deseado beds are still rarer and there is only one known specimen sufficiently perfect to permit skeletal reconstruction, a partial skeleton of *Thomashuxleya* from the Casamayor (paper reconstruction in Simpson, 1936; the skeleton has since been mounted).

The specimen here described was found by Justino Hernández, collected by me, and prepared and mounted by Albert Thomson. A life restoration was modeled by Miss France Baker, working at the American Museum as a student of Antioch College. John C. Germann drew the accompanying text-figures.

TAXONOMY.

Order Notoungulata Roth, 1903.
Family Hegetotheriidae Ameghino, 1894.
Subfamily Muñiziinae Kraglievich, 1931.
Genus *Propachyrucos* Ameghino, 1897.
Propachyrucos ameghinorum,[2] new species.

Type.—A. M. N. H. No. 29574, nearly complete skeleton.

Horizon.—Deseado, probably early Oligocene

Locality.—About 1½ kilometers south of the sheepherder's hut called "Las Cascadas," on the northwest side of the Meseta Canquel, in a small valley tributary to the Cañadón de las Víboras, approximately in Lat. 44 1/2° south, Long. 68 1/3° west, central Chubut Territory, Argentina.

Diagnosis.—Lower cheek tooth series of type 32 per cent larger than in type of *P. smithwoodwardi* and at least 20 per

[2] Dedicated to the memory of Florentino and Carlos Ameghino.

cent smaller than in type of *P. crassus*. I_3 and probably P_1 more reduced than in *P. smithwoodwardi*, and larger diastemata on both sides of P_1. About the size of *P. aequilatus* (or slightly larger), but without the relatively large anterior (premolar and) molar lobes said by Ameghino to characterize that species.

DESCRIPTION.

The dental formula is complete but $I\frac{2-3}{3}$, $C\frac{1}{1}$, and P_1 are vestigial. I^3 and the upper canine are represented by tiny pits that do not contain roots in this specimen and it is probable that the teeth, themselves, were lost in life and that the upper formula in a senile individual would be 2.0.4.3. I^2 is closely appressed to the greatly enlarged I^1 and was probably functional although small. There are large diastemata be-

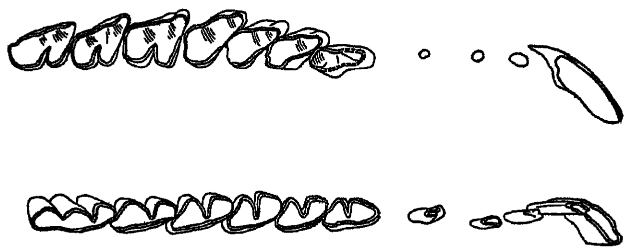


FIG 1. *Propachyrucos ameghinorum*, new species. Type, American Museum of Natural History No. 29574. Crown views of right upper and left lower dentitions. Lower dentition in small part completed by reversal from right side. I^{2-3} and C^1 are represented by alveoli. x 3/2.

tween I^2 and I^3 and between upper C and P^1, with a smaller diastema between I^3 and C. The premolars are obliquely triangular, increasing in width from P^1 to P^4. The internal faces are somewhat flattened but not grooved. Transition from P^4 to M^1 is abrupt. The molars have two distinct internal lobes, separated by a deep re-entrant fold, as in *Prosotherium* and the interatheres and markedly unlike *Pachyrukhos* and *Hegetotherium*. The outer wall is somewhat wavy, with poorly defined parastyle, paracone, and metacone convexities, but the groove between parastyle and paracone, often strong in interatheres and in some but perhaps not all species referred to *Prosotherium*, is vague and shallow. Cement is present, most definitely on the inner face, but is thin.

I_1 and I_2 are both enlarged, but I_1 is much larger, the longest diameter of a section being 5.1 mm. as against 3.0 mm. for I_2,

proportions about as in *Pachyrukhos*.[3] I_3, lower C, and P_1 are peg-like, tiny teeth but are present and functional. The canine is the smallest of the three, all of which are procumbent but decreasingly so from I_3 to P_1. There are short diastemata between I_3 and C, C and P_1, and P_1 and P_2. P_2 is unreduced and bilobed, differing little from P_3 except that the anterior lobe is relatively larger. P_3-M_3 have the usual hegetothere pattern, flattened lingually and bilobed labially except M_3, which is trilobed.

TABLE I.

Measurements in millimeters of dentition of *Propachyrucos ameghinorum*, type, A M. N. H No 29574.

I^1–M^3	55 4
P^1–M^3	32.1
M^1–M^3	16 2
Maximum diameter of transverse section of I^1	6 9
I_1–M_3	53 1
P_2–M_3	30 9
M_1–M_3	17 8
Maximum diameter of transverse section of I_1	5 1
Same, I_2	2.7

Upper cheek teeth, L=length of ectoloph, W=maximum transverse dimension (protoloph on molars):

	P^1	P^2	P^3	P^4	M^1	M^2	M^3
L	3.3	4 7	4 8	4 7	5 6	5 4	6.0
W	2.7	3.9	3 9	4 0	4 6	4 1	3 4

Lower cheek teeth, L=maximum length, W. ant =width of anterior lobe, W. post =width of posterior lobe (2nd lobe on M_3):

	P_2	P_3	P_4	M_1	M_2	M_3
L	5.0	4 9	4 9	5.4	5 5	7 5
W. ant.	2.2	2 5	2.5	2.3	2 4	2 3
W. post.	2 5	2 6	2.6	2.9	2 8	2 5

Width of 3rd lobe of M_3 . . . . 1 9

The skull differs little from the later hegetothere type thoroughly described by Sinclair (1909) and details need not be discussed at this time. It is almost exactly like the skull of *Prosotherium* (see Loomis, 1914). It resembles *Pachyrukhos* more than it does *Hegetotherium*, but both skull and mandible are more nearly equal in depth anteriorly and posteriorly than in *Pachyrukhos*, so that the head, in lateral view, has a less triangular or wedge-shaped contour than in the latter genus.

[3] Loomis's figures (1914) suggest that I_2 is the larger in *Prosotherium* but this is probably an effect of perspective. Ameghino (1897) states that the first incisor is enlarged in this genus

The cervical and dorsal vertebral series are complete and there appear to be only 12 dorsals although it is possible that the next vertebra, transitional morphologically, also carried a rib, giving 13 dorsals. 16 dorsolumbars are preserved and three more have been tentatively added in the reconstruction to give a total of 19 (probably d.12, l.7; possibly d.13, l.6). The formula is not completely known in any hegetothere, but Sinclair (1909) says that there are 8 lumbars in *Pachyrukhos*. The formula in *Interatherium* is d.15, l.7. Sinclair has reconstructed *Pachyrukhos* with d.15, l.8, and Loomis (1914) has reconstructed *Prosotherium* with the same formula. Because *Interatherium* is only quite distantly related to the hegetotheres and because our *Propachyrucos* surely has fewer than 15 dorsals, it is probable that these reconstructions have the column too long by at least two vertebrae. On the other hand it is possible that our reconstruction has too few lumbars and that the dorsolumbar total should be 20 or 21 rather than 19 as we have it. The neural spines of our specimen are strongly anticlinal as in *Pachyrukhos*. The anticlinal vertebrae is d.11, not d.13 as shown by Sinclair for *Pachyrukhos* or d.14 as shown by Loomis for *Prosotherium*, but neither of these reconstructions is reliable on this point. Sacrum and tail are missing in our specimen, but a short tail is probable in *Pachyrukhos* and we have restored the tail in the more primitive genus as slightly longer than in Sinclair's reconstructed *Pachyrukhos*.

The girdles and appendicular skeleton are so like *Pachyrukhos* that a detailed description of the minor differences that do exist is not necessary at this time. The resemblance to *Hegetotherium* is almost equally close, but the general build and proportions are more suggestive of *Pachyrukhos*. The one great difference from both Santa Cruz genera is that the tibia and fibula are unfused in the earlier genus, clearly a primitive character. These bones are more like *Hegetotherium* than like *Pachyrukhos*. The few elements in *Prosotherium* for which Loomis's data (1914) permit comparison are also generally similar, but with some apparent anomalies. The pelvis in *Prosotherium* seems to be relatively considerably larger. Loomis says that the third trochanter is on the posterior, not internal, side of the femoral shaft and so shows it in his figure, but this is so extraordinary that I suspect distortion or some peculiarity in orienting the bone. Loomis also shows the tibia as shorter than the femur in *Prosotherium*, whereas in all

TABLE II.

Skeletal dimensions in millimeters of *Propachyrucos ameghinorum* and compared species (All measurements are maximum lengths.)

	Propachyrucos ameghinorum, A.M.N.H. No. 29574	*Pachyrukhos moyani* A.M N.H. No. 9481, from Sinclair	*Interatherium robustum*, A.M.N.H No. 15401, from Sinclair
Skull	101	Ca 76½*	80
Humerus	68	56	60½
Radius	52	50	41½
Metacarpals:			
II	26	20	14
III	26½	22½	15½
IV	21	18½	13
V	15	14½	9
Femur	Ca. 85	Ca. 65*	59
Tibia	92	82	64½
Calcaneum	29	21	19½
Metatarsals:			
II	—	26½	16½
III	33	30	21
IV	31	26½	22
V	25	21½	17½

* Calculated from proportions in other individuals of this species.

other known hegetotheres the tibia is definitely the longer of the two. The bones were incomplete in Loomis's specimen, however, and the reconstruction may be erroneous. In the hindfoot of *Prosotherium*, Loomis shows digits II and III subequal and large, IV and V subequal and small. This is very unlike *Propachyrucos* or *Pachyrukhos*, although it resembles the much later, collaterally allied *Paedotherium*. Whether these discrepancies represent generic differences between *Prosotherium* and *Propachyrucos* or have some other explanation is not clear.

Size and proportions of *Propachyrucos ameghinorum* are compared with some later forms in Tables II and III and Fig. 2. *Prosotherium garzoni* has been similarly compared, but the data are omitted here because observations are incomplete and, in part, anomalous. *P. ameghinorum* is larger than its Santa Cruz allies and analogues.[4] The skull is relatively smaller in *Pachyrukhos* than in *Propachyrucos* but relatively larger in *Interatherium*.

[4] Deseado forms tend to be larger than their later relatives, although more primitive, a peculiarity that merits further study.

TABLE III.

Ratios of lengths of skeletal elements in *Propachyrucos ameghinorum* and compared species. (Specimens the same as in Table II.)

	Propachyrucos ameghinorum	*Pachyrukhos moyani*	*Interatherium robustum*
Humerus / Radius	1.31	1.12	1.46
Radius / MC III	1.96	2.22	2.68
MC III / MC II	1.02	1.12	1.11
MC III / MC IV	1.26	1.22	1.19
MC III / MC V	1.77	1.55	1.72
Femur / Tibia	Ca 92	Ca. 79	91
Tibia / MT III	2.79	2.73	3.07
MT III / MT IV	1.07	1.13	.95
MT III / MT V	1.32	1.40	1.20

In *Propachyrucos ameghinorum* the radius is shorter relative to the femur and the tibia is shorter relative to the femur than in *Pachyrukhos*. The greater elongation of the distal segment in the later form apparently represents progressive cursorial or, probably, saltatory adaptation. In *Interatherium* the radius is less elongate, relatively, than in either of these hegetotheres, but the hind limb proportions are about as in *Propachyrucos*. The forefoot is more elongate relative to the radius in *Propachyrucos* than in *Pachyrukhos*, but this is a function of the shorter radius. Elongation of the foot relative to the forelimb as a whole is almost the same in the two genera and no evolutionary change is indicated. The forefoot in *Interatherium* is decidedly shorter than in hegetotheres.

The order of length of the metacarpals and of the corresponding toes is III>II>IV>V in *Propachyrucos*, *Pachyrukhos*, *Paedotherium*, and *Interatherium*, but there are distinct differences of proportion. In *Pachyrukhos* the manus is nearly mesaxonic, with digit III definitely longest, II and IV both stout and subequal, and V smaller but not clearly reduced. In *Prop-*

achyrucos, II and III are of almost equal length and stoutness, IV is distinctly smaller, and V is more reduced than in *Pachyrukhos*. The proportions in *Propachyrucos* are, in fact, more like those of the far later *Paedotherium* and it appears that *Propachyrucos* is more specialized in the manus than is *Pachyrukhos*. This is not too anomalous. *Propachyrucos* is not, I

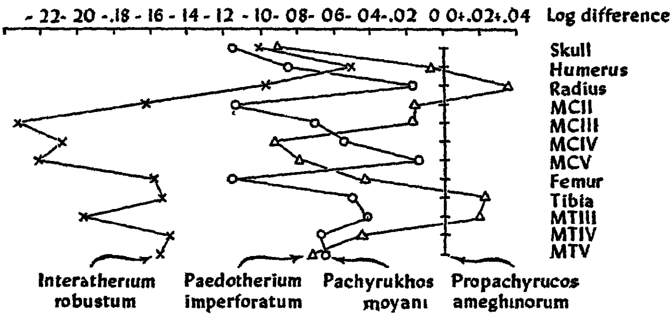


FIG. 2. Ratio (logarithm difference) diagram of lengths of skeletal elements, as labeled, in three hegetotheres and an interathere Based on single specimens as in Table II

think, ancestral to *Pachyrukhos* and there is no reason why the generally more primitive genus should not be precocious in some respects.

In all hegetotheres and typotheres, the hind-leg is much longer than the fore, and *Propachyrucos* is no exception. The length ratio of humerus plus radius plus third metacarpal to femur plus tibia plus third metatarsal is .70 in our specimen. In a specimen of *Pachyrukhos moyani* it is .73, showing a relatively less elongate hind-limb in the later species, but this is probably within the range of individual or specific variation. In Kraglievich's specimen of *Paedotherium imperforatum* the ratio is .70, the same as in our much older species. A specimen of *Interatherium robustum* has the ratio .81 and the fore and hind limbs are distinctly more nearly equal in that genus than in the hegetotheres.[5]

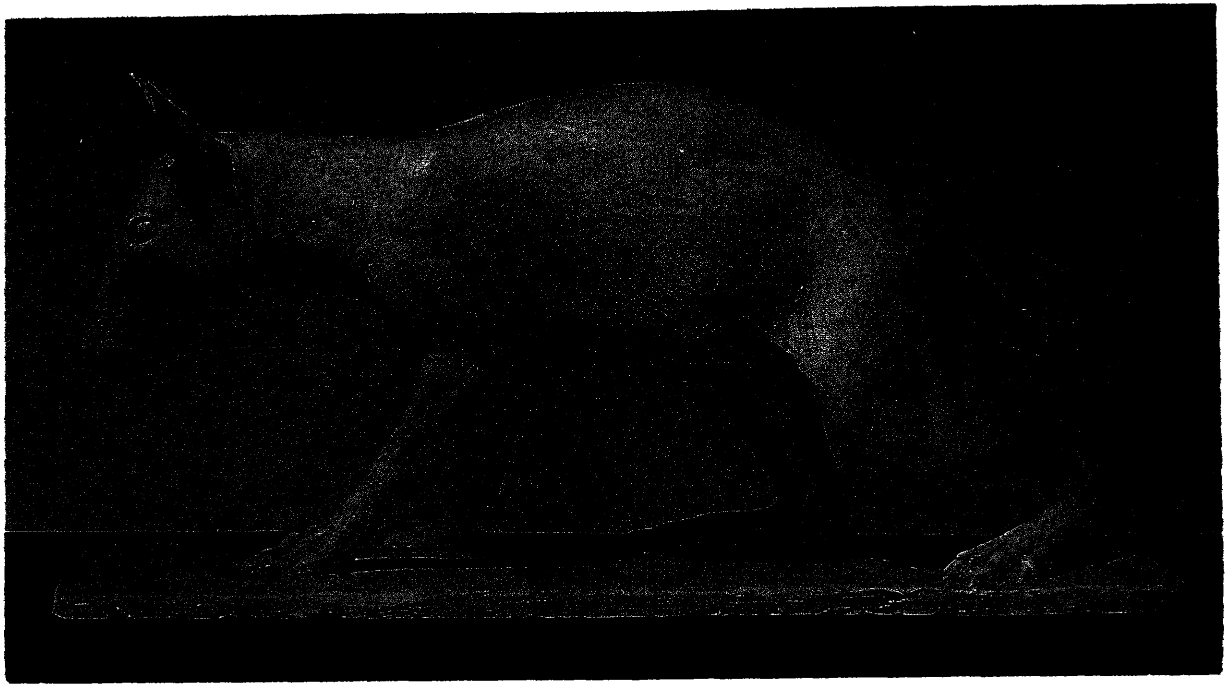
[5] Kraglievich (1926) has pointed out that in *Tragulus* the hind limb is even more elongate than in *Paedotherium* The ratio that I use (not quite the same as Kraglievich's but bearing on the same characteristic) is 68 for Kraglievich's specimen of *Tragulus* and probably is not significantly different from *Propachyrucos* However, this has little bearing on the pose of the animal (see below), because *Lepus*, so different in pose from *Tragulus* and so much more like *Propachyrucos* in habitus characters, has ratios in the same general range

The second metatarsal is incomplete in our specimen of *Propachyrucos* but it was clearly more slender and probably shorter than IV. The size relationship for the metatarsals and the toes as a whole is III>IV>II>V. In *Pachyrukhos* II and IV are nearly equal in length. III is longer but no stouter and V is small but less reduced than in *Propachyrucos*. Thus *Pachyrukhos* has an essentially mesaxonic and, except for the loss of I, unreduced pes. In *Paedotherium*, however, II has become as stout and almost as long as III, IV is decidedly smaller than II, and V is much reduced, almost vestigial. *Paedotherium* is tending toward a pseudo-paraxonic type, with the weight borne by II and III, not by III and IV as in the true paraxonic pes. *Pachyrukhos* is mesaxonic, although it provides an appropriate base for the pseudo-paraxonic type. *Propachyrucos* belongs to neither type but more resembles, without belonging strictly to, the true paraxonic pattern. This complex of cross-specializations is further complicated by the fact that the forefoot of *Propachyrucos*, unlike the hindfoot, does approach the peculiar and specialized pseudo-paraxonic (II-III axis) type.

AFFINITIES.

Propachyrucos smithwoodwardi Ameghino, 1897, type of the genus, was based on a lower jaw with the dentition very like that of *Prosotherium*, *Pachyrukhos*, and *Hegetotherium* but differing from the first and second of these genera in the retention of the full dental formula and from the second and third in the unreduced, molariform P_2. Our specimen has these presumably generic characters of *P. smithwoodwardi* although it differs too much in size and in some other details to be placed in the same species. *P. crassus* Ameghino, 1897, was defined only on the basis of size, which is enough larger than the present specimen to make specific identity most improbable. The type, which has not been figured or described beyond a statement as to size, apparently included only P_2–$_3$ and it is not clear that the genus can be recognized from these teeth alone or, consequently, that *P. crassus* does belong to *Propachyrucos*. The same doubt arises with regard to *P. aequilatus* Ameghino, 1901, also unfigured, apparently based on a jaw fragment with P_4-M_3, teeth that can with difficulty, or not at all, be distinguished generically among hegetotheres. The only morphological character given was that in *P. aequilatus* the

Propachyrucos ameghinorum, new species Type, American Museum of Natural History No 29574. Mounted skeleton, left side. X 1/3



Propachyrucos ameghinorum, new species Life restoration by France Baker, under the direction of John C. Germann and the author, based on the type skeleton as mounted (Plate 1). Original model X 1, this reproduction X ⅓

anterior and posterior lobes of the cheek teeth are of equal size while in other species of *Propachyrucos* the anterior lobe is smaller. The anterior lobe is somewhat smaller in our specimen, but the difference is not marked, nor is it in Ameghino's figure of *P. smithwoodwardi* (1897, fig. 11, the only figure of *Propachyrucos* hitherto published). In *Prosotherium* the anterior lobe apparently tends to be somewhat larger, and it is not clear from the published data why *P. aequilatus* was not placed in *Prosotherium*, in which case it would probably be found synonymous with *P. garzoni*. Loomis (1914) described no material of *Propachyrucos*.

The only other species hitherto referred to *Propachyrucos*, as far as I know, is *P. schiaffinoi* Kraglievich, 1932, based on an upper jaw fragment from the Santa Lucía beds of Uruguay. This was not directly comparable with Ameghino's species, all based on lower jaws, but was tentatively placed in *Propachyrucos* because it retains P^2 and probably P^1 but otherwise is somewhat (not precisely) similar to *Pachyrukhos*. This specimen is however, radically unlike the upper jaw of *Propachyrucos ameghinorum*, for instance in the absence of internal folds on the molars, and certainly does not belong in the same or even a closely related genus. Since the reference of *P. ameghinorum* to *Propachyrucos* is fairly well established it follows that "*P.*" *schiaffinoi* almost surely does not belong to *Propachyrucos*.[6]

Prosotherium Ameghino, 1897, was described at the same time as *Propachyrucos*, based mainly on a complete palate although the lower dentition was briefly described, without illustrations. No direct contrast between *Prosotherium* and *Propachyrucos* was given by Ameghino, but his definitions involve the distinction that the lower canine and P_1 are absent in *Prosotherium*, a long diastema being present, while these teeth are present in *Propachyrucos* and there is, according to Ameghino, no diastema. Loomis (1914) had excellent material of *Prosotherium* but none of *Propachyrucos*, so that he could only add that I_3 is absent in *Prosotherium*, but that P_1 is present. Our specimen shows that *Prosotherium* and *Propachyrucos* are

[6] This also removes the basis for Kraglievich's correlation of the Santa Lucía beds with the Deseado. It is unlikely that "*P.*" *schiaffinoi* is pre-Deseado, but on present evidence it might belong almost anywhere from the Deseado to the Pleistocene.

very closely related and perhaps casts some doubt on whether they should be distinguished as separate genera

Even in *Propachyrucos smithwoodwardi*, as figured by Ameghino, I_3, C, and P_1 are vestigial and there are small diastemata anterior and posterior to P_1. In the type of *P. ameghinorum* these teeth are still further reduced and the diastemata are larger. In the upper jaw I^2 is vestigial and C still more so, apparently lost in the adult. From Ameghino's querying I_3 in *Prosotherium* and saying that P_1 is absent, while Loomis says I_3 is absent and P_1 present, it is probable that these vestigial teeth vary in that genus, whether individually, ontogenetically, or inter-specifically. Apart from the presence or absence of these vestigial teeth, *Propachyrukhos* and *Prosotherium* are very similar The other parts of the dentition and the skulls hardly seem to warrant generic separation. There are some apparent differences in the skeletons, as has been noted briefly above, but the significance of these is not altogether certain. There are also several species, or supposed species, of each genus in which the possible generic distinctions are poorly or not known. The separation is thus not clear-cut. There appears to be a complex of species, all closely allied, and whether division into *Propachyrucos* and *Prosotherium* is valid, sufficient, and natural is not as yet well established.

Propachyrucos ameghinorum has the skull and dentition of the same size as *Prosotherium garzoni*, but whatever the eventual disposition of the genera, it is sufficiently clear that these species are distinct.

Prosotherium and *Propachyrucos*, together, are distinguished from most other hegetotheres especially by the fact that the upper premolars are not molariform and that the upper molars have strong internal grooves, resembling interatheres (true typotheres) more than typical hegetotheres. *Prohegetotherium*, contemporaneous with *Prosotherium* and *Propachyrucos*, was more typically hegetothere in this respect.[7] Ameghino (1897) considered *Propachyrucos* the immediate ancestor of *Pachyrukhos* and Loomis (1914) assigned this position to *Prosotherium*.

[7] And so, perhaps, were earlier, Musters, forms Ameghino named three genera of hegetotheres from the Musters, but their characters are dubious His descriptions were brief, no figures were given, and the specimens could not be found in the Ameghino Collection when I made a search for them.

It is evident that *Propachyrucos*, *Prosotherium*, and *Pachyrukhos* are allies, but it is not clear that either (or both) of the first two is ancestral to the last. The upper cheek dentition of the named Deseado genera is sharply different from that of *Pachyrukhos*. The difference could readily be spanned by evolution, but the time lapse is not very great, intermediates are unknown and dentitions more like *Pachyrukhos* do occur in the Deseado.

The fate of the *Propachyrucos-Prosotherium* line may be revealed by *Muñizia*, and the origin of that puzzling genus may be explained by the comparison. *Muñizia* was described by Kraglievich in 1931 on the basis of a maxillary fragment from the Entrerrios beds of the Paraná. The molars are like those of interatheres, but the root of the zygoma is hegetothere-like. Kraglievich gave more weight to the molar structure and assigned this apparently synthetic type to the Interatheriidae but to a distinct subfamily, Muñiziinae. In a passing note (Simpson, 1932, p. 10), I expressed skepticism regarding so remarkable a reversion of the highly characteristic and specialized interathere jugal and suggested that *Muñizia* might be either a hegetothere with molars convergent toward interatheres, or a line distinct [from either] since the early Tertiary. Patterson (1934, p. 136) pointed out that the molars of *Muñizia* are similar to those of *Prosotherium* and concluded that *Muñizia* is probably a hegetothere that has preserved the primitive molar pattern, lost in *Pachyrukhos* and *Hegetotherium* (and in *Paedotherium*, the *Pachyrukhos*-like contemporary of *Muñizia*). The present restudy suggests that my two alternative suggestions and Patterson's third are all true, that *Muñizia* is a hegetothere, of a line distinct since the early Tertiary, with molar pattern departing from an earlier basis than the *Pachyrukhos* pattern, and to some extent convergent toward interatheres.

The evidence tends to show that two groups of hegetotheres can be distinguished at least from the Deseado to the Entrerrios, and perhaps earlier or later for one or both. One group, with less molariform premolars and interathere-like molars, includes *Propachyrucos*, *Prosotherium*, and *Muñizia*. The other, with molariform premolars and non-interathere-like molars, includes *Pachyrukhos*, *Hegetotherium*, and *Paedotherium*. Each group may contain other, at present dubious, genera, and each seems to have more than one line of precise descent, yet they

are probably phyletic units. This considerably lessens the probability that *Propachyrucos* is especially related or ancestral to *Pachyrukhos*, although it is clear that all the genera, of both groups, are quite closely similar despite their rather long separation.

If *Muñizia* is a descendent of the *Propachyrucos-Prosotherium* group, the advances visible in the single known fragment of the later genus indicate a considerable increase in size and the development of a small reentrant enamel fold at the antero-internal edge of P^{3-4}. These premolars (the others are unknown) retain their triangular contour and are not molariform despite this slight complication. The zygomatic root may be somewhat more horizontal than in the Deseado genera and its posterior rim is more anterior, making the root relatively shorter, but the significance of these differences is questionable.

In the light of the evidence here summarized, I suggest that the subfamily Muñiziinae Kraglievich be retained, but in the family Hegetotheriidae, not Interatheriidae as proposed by Kraglievich. In addition to *Muñizia*, *Propachyrucos* and *Prosotherium* are referred to the Muñiziinae

RESTORATION.

The restored life-model by Miss Baker is of the natural size and is in the same pose as the skeleton. The animal is shown as alert but not in motion, just preparing to step away slowly, with both forefeet and the off hindfoot planted and the near hindfoot extended posteriorly, with the heel raised.

The forefeet are shown as digitigrade and the hindfeet as plantistat, rising to the digitigrade position in leaping or rapid progression. This question of foot posture is always a difficult one in mounting skeletons of animals without close allies or exact analogues in the recent fauna. The anatomical evidence is often equivocal and, as far as I know, no completely conclusive criterion has been found. Except in extreme cases, a habitually plantigrade foot can usually assume a digitigrade position and some digitigrade feet can easily be placed in either a plantigrade of an unguligrade position, especially when dealing only with the skeleton. In *Propachyrucos*, the hind feet could be mounted in the plantigrade, digitigrade, or unguligrade position, but when the articulation is placed in what seems the easiest, most relaxed way, with the tibia on the middle

of the astragalar trochlea, the foot tends naturally to be plantigrade. The terminal phalanges are more claw- than hoof-like. They are not fissured, but they are long, sharp, and compressed laterally, not dorso-ventrally. As far as analogy can be followed, the whole build of *Propachyrucos*, including the dentition, skull, and limbs, seems to me most like the leporids among recent mammals. There are, of course, striking differences also, but the resemblance in habitus seems to warrant the opinion that in *Propachyrucos*, as in most leporids, the forefoot was digitigrade and the hindfoot plantigrade at rest, i.e. plantistat,[8] but likewise digitigrade in locomotion, or in rapid locomotion.

This was nearly the opinion of Sinclair (1909) regarding *Pachyrukhos*, which he also considered analogous with leporids and called plantigrade as to pes and digitigrade as to manus. Kraglievich (1926) however, argued that *Pachyrukhos* was digitigrade, almost subunguligrade, and that its probable descendent *Paedotherium* was fully unguligrade. As evidence of unguligrady in *Paedotherium* he stressed the deep astragalar trochlea, the presence of strong metapodial keels, the hoof-like terminal phalanges, and the analogy with *Tragulus*. Whatever may be true of *Paedotherium*, these arguments do not apply to *Propachyrucos* or *Pachyrukhos*. The astragalar trochlea is shallower in them. The metapodial keels are weaker and ventral only; they are, in fact, like so many other habitus characters, almost exactly as in leporids. The terminal phalanges, especially in *Propachyrucos*, are more claw-like than hoof-like, although not fissured. Even for *Paedotherium* the analogy with *Lepus* seems to me much closer than the analogy with *Tragulus*, and this is still more obvious for the earlier genera. It is quite possible that Kraglievich is right, but the evidence does seem to incline somewhat to the view that *Propachyrucos* and *Pachyrukhos* were digitigrade with the pes plantistat, and that *Paedotherium* was more fully digitigrade, possibly subunguligrade, and digitistat.

The hypothetical external features have been treated con-

[8] This term, proposed by Virchow in discussing the penguins, means that the tarsus normally touches the ground when the animal is standing but relaxed. Plantigrade properly means that the tarsus touches the ground when the animal is walking, and this is not true of all plantistat animals Man is plantistat, but optionally either plantigrade or digitigrade, depending mainly on speed of locomotion.

servatively in the restoration of *Propachyrucos*. The hair is shown as short and neither woolly nor fluffy, a supposition as reasonable as any other and making a more interesting restoration because the muscles are more visible and the modeling more plastic. The ears are shown as large. The sense of hearing was almost surely important and acute in this as in other small notoungulates. Rabbit-like ears have, however, been avoided in order not to exaggerate resemblance to the leporids and to keep clear in the minds of museum visitors the fact that this animal is not a sort of rabbit. For similar reasons the short tail is moderately tufted and not puffed.

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COMMENTS ON "GEOLOGY OF LAU, FIJI."

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ABSTRACT Nine authorities have cooperated in making the recently published report on the geology of eastern Fiji. Among the particularly noteworthy results of their study are: (1) the mid-Miocene age of the emerged Futuna limestone, which is visible in most of the Lau archipelago; (2) the richness of the limestone in dolomite; (3) field evidence forbidding application of the Darwin-Dana subsidence theory in explanation of the bedded, somewhat coralliferous limestone; and (4) evidence that in each island the limestone is a veneer on a volcanic pile, which in each of a number of cases had suffered marine abrasion just before the deposition of the carbonate rock. The present paper briefly discusses. (1) the cause of the dolomitization; (2) the meaning of the fact that the emergence of the many islands in post-Futuna time was only slightly differential—a new argument against the subsidence theory of the living coral reefs; and (3) the thesis that the glacial-control theory of *these* reefs is itself an "antecedent-platform theory," and, in the writer's opinion, the best version of it.

IN 1929 J. E. Hoffmeister, H. S. Ladd, and H. L. Alling reported on a visit made to the famous Falcon Island of the Tonga group; they were impressed by the speed with which this recently emerged, pyroclastic mass was truncated by the ocean breakers, forming a platform suitable for the plantation and upward growth of an atoll reef. Three years later Hoffmeister published his field study of Eua Island, also in the Tonga group. In 1934 Ladd gave the results of his field study of Vitilevu Island in western Fiji. The recently issued "Geology of Lau, Fiji," by Ladd and Hoffmeister is the product of still another field study, the chief aims of which were to "tie the geological history of Tonga to that of western Fiji," and "to obtain data bearing on the coral reef problem." (See references 1 to 4.)

The "Geology of Lau, Fiji" is an excellent example of the value of coöperative research by specialists and also illustrates the principle that experience gained in the field study of one Pacific archipelago gives special power to the same workers who go to wrest the geological secrets from other island groups. The Lau report, while corroborating many conclusions of earlier visitors to these islands, records a wealth of new facts that give food for thought. The details are legion and a full summary is not here attempted; the intention of the present commentator is rather to emphasize a few of the notable products of the field and laboratory study.

One outstanding discovery is that 15 out of the 25 more important islands of the Lau group, spread over an area measuring about 100 miles by 150 miles, show outcrops of bedded (only locally coralliferous) limestone, called the Futuna formation and referred to the mid-Miocene (stage *f* of the East Indian stratigraphic column). Of this limestone 32 chemical analyses were made, the specimens coming from Fulanga, Ongea, Kambara, Katafanga, and Namuka. Every specimen was found to be rich in magnesia and in most cases the rocks can be fairly classed as dolomitic. Since some are unaltered or only slightly altered, "it is difficult to see how the magnesia could be introduced with so little recrystallization. The possibility of original deposition of magnesia with calcium carbonate does not seem to be entirely out of reason" (Sanders and Crickmay, p. 257 of the Lau report).

Is not the last statement an under-statement, somewhat too cautious? It does not mean that rhombs of dolomite are formed directly from sea water, either inside or outside animal or plant bodies; more probable is speedy reaction of initially exsolved aragonite and calcite with the magnesia-rich water, to form the double carbonate. In this sense no student of an old open-ocean dolomite or magnesian limestone should object to the idea of large-scale "original" deposition of magnesium carbonate on the ocean floor.

In the report there seems to be no mention of the reason why the magnesia-rich limestone was precipitated instead of a more purely calcareous sediment. For the "original" deposition of abundant magnesium carbonate on the floor of the open ocean several variables in the physico-chemical conditions can be ruled out—namely, pressure, salinity, and mere duration of exposure of first-stage carbonate to sea water. The one variable to be suspected as a major control is temperature. In a survey of the dolomite problem, Blackwelder found evidence for this conclusion. It is supported by the experiments of Leitmeier, Walker and Gerrie, and others, and by (unpublished) experiments of the present writer with alkalized sea water kept for 10 weeks at blood temperature. In consonance is Clarke's discovery that the content of magnesium carbonate in skeletons and shells of many marine organisms increases with increase of temperature for the water in which they live (6 to 8).

A question is at hand: was the tropical ocean warmer in Futuna (mid-Miocene) time than it has been normally since,

say, Jurassic time? No one can answer that query with assurance, but it is worth noting that the Miocene limestone of Christmas Island in the Indian Ocean and even Miocene limestone as far north as Japan are rich in magnesia, if not definitely dolomitic. Speculation can go further and pose two other questions: (1) Can this particular stage in Miocene oceanography be correlated with the celebrated Miocene stage of extra-warm climate in Greenland; (2) is the dolomitic limestone beginning at the depth of 640 feet in the outer part of the Funafuti atoll of Futuna age? Is the assignment of such a date for the deposition of this material really disproved by the fossil content of the Funafuti column?

In their summary of the geological history of Lau, Ladd and Hoffmeister make clear that some long-standing views concerning the group need correction. They write: "Almost without exception, the small subcircular islands in Lau have well-developed basin shapes, and many of the islands that are partly formed of volcanic rock have such basin shapes. Early investigators were impressed by these striking basins and interpreted them as elevated atolls. We have shown that in Fulanga, Namuka, and, possibly, Kambara and Ongea these interpretations appear to be correct. Detailed examinations of the limestones of these islands offer some support to the atoll interpretation. The basin shapes of these islands are probably due primarily to organic growth, subsequently modified by solution and other erosive processes." On the other hand, other islands do not "show clear evidence that they were once atolls, hence their basin shapes cannot be directly attributed to organic growth" (p. 168). The basins in islands of this second category are explained chiefly by subaerial solution, after emergence, an idea shared by Gardiner in the case of Fulanga.

Ladd and Hoffmeister "believe that Lau's reefs, both Recent and elevated, can be most satisfactorily explained without any form of Darwinian subsidence" (p. 173). They add: "No thick elevated reefs such as are demanded by the subsidence theory could be located, though we carefully examined islands from which such reefs had been reported by earlier workers. Since the Lau limestones were formed their history has been mainly one of elevation and erosion; wave cut terraces, leeward erosion remnants, and veneering reefs support this interpretation" (p. 174). Their argument against an application of the Darwin-Dana theory to the reefs living in eastern Fiji is strengthened by a deduction that emerges from the field facts recorded in

their report. The mid-Miocene Futuna limestone rests on piles of volcanic rock. At its base the limestone carries pebbles and boulders torn out of the volcanics. The contact of the two formations is visible in most of the islands; a good number of examples are listed in the following table, which names islands surrounded by living barrier reefs, gives the widths of the corresponding lagoons, and marks with the letter X those islands where the contact of volcanics and limestone is visible.

Island	*Width of lagoon* (*miles*)
Exploring Isles	
Vanua Mbalavu (X)	21
Malatta (X)	
Susui (X)	
Thikombia (X)	
Avea (X)	
Mango (X)	½
Tuvutha (X)	½
Katafanga (X)	3
Oneata (X)	5
Lakemba (X)	5
Ongea	2
Yangasa	8
Namuka	1
Mothe and Karoni (X)	1

In every case the surface of contact is close to the existing sealevel. Evidently, then, any subsidence of these well separated and individualized masses of rock, if the subsidence were real, could not have been markedly differential. But the subsidence theory demands widely different degrees of sinking in the Lau archipelago. For, according to this theory, the width of atoll or barrier lagoon, located on a volcanic pile, should in general vary directly with the amount of sinking of each of these more or less conical piles. The second column of the table shows the width of the lagoons to range from ½ mile to more than 20 miles. This failure of the subsidence theory to meet the facts in an area 150 miles long and scores of miles wide is particularly serious, when the theory is applied to the young, living reefs.

Of course that evidence does not mean that some atolls and barrier reefs were not formed by local or regional subsidence in pre-Pleistocene time. If, as Ladd and Hoffmeister think, the Miocene limestones of Fulanga and Namuka are atoll formations, the subsidence theory might offer a reasonable explanation of these local thickenings of the Futuna limestone, though

even in these instances Suess's idea of a positive eustatic shift of sealevel during the Miocene is still worthy of consideration.

In 1944 Hoffmeister and Ladd advocated in detailed argument "the antecedent-platform theory" of the world's coral reefs, which they have preferred throughout the fifteen years since they visited Falcon Island. This paper may be regarded as a supplement to the Lau report. On page 389 of the paper (9) we read: "The Antecedent-Platform theory holds that any bench or bank—even one not 'smooth'—that is located at a proper depth within the circumequatorial coral-reef zone can be considered a potential coral-reef foundation and that, if ecological conditions permit, a reef could grow up to the surface without any change of ocean-level. This is a general principle that applies to coral reefs of all ages—preglacial, glacial, and postglacial . . . Many of those who postulate an antecedent platform seem to feel that a second requirement—a rising sea-level—is also necessary. The rise in sealevel may be due to an actual rise in ocean-level or to a sinking of the land. It is our belief that such a sea-level change may stimulate reef growth, but we hold that it is not *essential* for the formation of a flourishing barrier or atoll reef."

Ladd and Hoffmeister have in fact made it abundantly clear that the living reefs of eastern Fiji do rest on platforms cut-and-built by the ocean waves, operating on volcanic piles. The cutting and building took place in pre-Futuna time, millions of years before the Pleistocene Glacial period. This region thus illustrates one of the chief postulates of the glacial-control theory, which, however, assumes that the platforms now surmounted by living reefs were cut or built or cut-and-built during exposure to wave-action for long periods included between the Pre-Cambrian and the Pleistocene. Until the reef-building, wave-resisting corals were evolved, the ancient platforms were developed with surfaces well below sealevel. On these platforms local, pre-Pleistocene reefs may have grown up to sealevel, but, as long as the new masses of reef material lay between sealevel and the hundred-fathom isobath, they remained weak structures and, with the death of defending corals on their faces, were liable to complete destruction by the low-level abrasion of the Pleistocene glacial stages. In other words, the low-level abrasion merely smoothed platforms which had been prepared long before the Pleistocene or cut smooth platforms in thoroughly weak rocks—unconsolidated sediments and pyroclastics. This brief re-statement of one aspect of the

glacial-control theory is made because of the mistaken ideas of Ladd and Hoffmeister, W. M. Davis, and others concerning the history of the platforms whose recognition is so vital a part of the glacial-control theory.

The Lau report is not quite clear as to the origin of the Fijian platforms. There are repeated references to truncation of the volcanic piles by pre-Futuna wave-action, a process that is practically ineffective at 50 fathoms, a depth which, according to Ladd and Hoffmeister, is not too great for the beginning of growth of barrier or atoll reef. On the other hand, they report cases where pelagic shells and deep-water algal growths built up the platforms to the "zone of coral reef growth," thus adopting one postulate in Murray's explanation of atolls.

Presumably the first of the two methods of final preparation of platforms would apply to many, if not most, of the greater atolls and barrier-reef structures of the world. Such cases represent a fundamental difficulty for the antecedent-platform theory as phrased by Ladd and Hoffmeister. For, long before abrasion could bring the platform surface down to the 50-fathom level or even to the 30-fathom level, coral larvae could settle on that deepening surface of erosion, form defending reefs, and so prevent further lowering of that surface. To have produced a cut-and-fill platform at the depths corresponding to those of the flat-floored lagoons of the great atolls and barriers (including the Exploring Isles example in Lau), there must have been an interruption in the lusty growth of reef corals over most of the tropical zone. Such interruption is provided for by the glacial-control theory, but is not provided for in the statements of the platform idea by Ladd and Hoffmeister, Agassiz, Andrews, Chamberlin, Guppy, or Wharton. To the present writer the glacial-control theory is the only workable, published form of the antecedent-platform theory, and among its merits is its success in accounting for another vital fact—the comparative narrowness, and therefore youth, of nearly all the coral reefs now living in the world.

If some of the Lau volcanic piles were crowned with atolls of mid-Miocene age and at a time when their platform surfaces were near enough to sealevel to permit the rounding of pebbles and boulders—the conclusion of Ladd and Hoffmeister—there must have been failure of vigorous reef-growth just before the beginning of Futuna time. Here, then, we would have to assume a time hiatus in reef growth, a hiatus which had nothing to do

with the Pleistocene chilling and muddying of the tropical water as its level slowly fell because of continental glaciation. Perhaps such an interruption of coral growth in the warmer parts of the mid-Miocene ocean might be attributed to the relatively high temperature which has been suggested as a cause for the enrichment of the Futuna limestone in magnesia. Many experiments by Mayor and by Edmondson have proved that, if the water temperature rises to 90° F., many species of reef-building corals are killed (10, 11). That temperature is only about 10° higher than the maximum temperature of surface water in the Lau region. Is it, then, not possible to find in excessive warmth a second reason for a temporary removal of defending reefs in the *warmer* regions of the tropical belt?

A final remark: While the author of the glacial-control theory believes it to be the best general explanation of the living reefs of the world, he would be the last to deny that some local reefs, barrier and atoll, have in past geological time been developed according to the terms of the subsidence theory; or to deny that possibly some platforms for coral reefs have been prepared under conditions different from those visualized by the glacial-control theory.

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DISCUSSION.

HOLMES ON PHYSICAL GEOLOGY.

A Review.

There has recently appeared *Principles of Physical Geology,** by Dr. Arthur Holmes, Professor of Geology at Edinburgh University. This is a welcome text, written by an author who has long been noted for clear, forceful presentation of difficult themes in earth science. Here he has run true to form and given to college students and other cultivated souls an admirable, richly illustrated introduction to the facts known about the topography of the earth and its more accessible, superficial structures. As a descriptive summary the book has many worthy rivals, but more daringly and persistently than any other one-volume treatment of the complex subject, it emphasizes the truth that real understanding of the world of ascertained facts must ultimately be founded on knowledge of the nature of the earth's deep interior and the processes there operative during geological time. For the attempt to connect the visible and "known" with the explanatory invisible Professor Holmes is well fitted, for he is widely experienced not only in the teaching of general geology, in field geology, and in the scientific study of rock species, but also in important phases of geophysics and geochemistry. Like all other introductory textbooks this one could not cover the vast field in detail. Its author must have felt many a pang in deciding what facts, deductions, and speculations had to go without discussion or even mention. It is just as natural that Professor Holmes should stress some principal conclusions to which his own researches had led him, though in every instance he has been careful to note the provisional character of his conclusion

The professional geologist must be particularly interested in Part 3 of the book, dealing with "Internal Processes and Their Effects." There will be found a digest of modern Swiss, French, and German views regarding Alpine geology, which is brief but of remarkable clarity. This masterly condensation of a long and enormously complicated history is a good example of the author's objectivity and skill in presentation That he is not afraid of revolutionary ideas is shown in the last chapter, where he outlines the hypothesis of continental drift. For this boldness he will doubtless be chastised by some "tender-minded" geologists, but, in view of the widespread popular and professional interest in this hypoth-

* Ronald Press, New York, xi+532, with 95 plates and 262 text illustrations (1945).

esis, it is at least a question whether the relevant ideas of Taylor, Wegener, du Toit, and others should be omitted from even an elementary book on physical geology. While tolerant of the hypothesis himself, Professor Holmes has wisely guarded his readers against putting final faith in it. He writes (p. 508): "It must be clearly realised, however, that purely speculative ideas of this kind, specially invented to match the requirements, can have no scientific value until they acquire support from independent evidence." Like many other passages, this last chapter well illustrates our author's teaching, that the student should keep an open mind on all the greater problems about the earth.

Limitations of space in the book prevented full discussion of some of Professor Holmes's fundamental postulates. One of these is the existence of only two main layers, the "granitic" and "basaltic" in the continental sectors of the earth's "crust", taken to be 35 kilometers thick—the conclusion of Dr. Harold Jeffreys. No mention is made of the possibility that the lower of these two layers is a quartz-diorite or an allied, non-basaltic type of rock, and that there is a third crustal layer composed of piezo-crystallized basalt and extending downward for some distance below the base of the second layer. Professor Holmes does not follow Jeffreys in describing the material just beneath the "crust" as dunite, but suggests (p. 372) that this material is "possibly comparable in composition to peridotite but probably differing in many respects from any known surface rocks" Such is the planetary stuff which, under the name of "the substratum", is thought to extend all the way from the bottom of the thin "crust" down to the iron core of the earth, at 2900 kilometers from the surface The state of the material is not indicated, but the high density (3.4 at page 380 and 3 3 at page 441) seems to imply crystallinity. If the material is crystalline, it would be hard to deny it finite strength. Further, the 1600-mile shell is supposed to be homogeneous to the degree that it could be overturned, at certain epochs of geological time, by single-step thermal convection. This is a parlous assumption, in view of the probability that during its formation our planet became layered, the intrinsic density of its shells increasing with increasing depth from the surface. Just such layering is exemplified in many thick sills, lopoliths, and other eruptive bodies exposed to the geologist's hammer.

Incidentally we note that an argument for single-step convection in the 1600-mile shell is seriously weakened if we accept two suggestions made in the book. On page 373 we read that there are possible changes of intrinsic density with corresponding changes of "composition or of state (e.g. from crystalline to glassy)" at the depth of 400 to 700 kilometers below the earth's surface. And it

is not made clear that potential for thermally-incited convective overturn of the thick "substratum" shell could be attained if its material "behaves as a plastic substance (with a little strength) rather than as a viscous substance (with no strength)." (p. 33.)

To this reviewer it seems right to keep among our speculations the idea of overturn of a subcrustal shell, but only on the assumption that that shell is comparatively thin, relatively homogeneous in a chemical sense, and so hot as to be in a vitreous and strengthless condition. It is also conceivable that the overturn of a deep-lying shell might, in the young, hot earth, compel the convective overturn of the layer immediately above; in other words, that what may be called tandem convection in a succession of sub-layers in the 1600-mile shell helped in the present organizatizon of the deep earth and in the development of its surface structures. The importance of a decision as to the reality of occasional single-step overturns of complete sectors of the shell is shown in Professor Holmes's attempts to find in these movements explanation for: (1) the high stand of the continents above the ocean floor (p. 20); the making of mountain chains (p. 377) (3) the origin of volcanism in the broad sense (p. 484); and (4) the migration of continental blocks and the origin of the Arctic, Atlantic, and Indian oceans (p. 506).

Professor Holmes definitely rejects the idea of a basaltic layer in his "substratum", makes no mention of the possibility of an eruptible basaltic layer in past geological time, and regards the origin of basaltic magma as an unsolved problem (p. 480). If his picture of the earth's "crust" and his preferred thermal gradient along the outer part of the earth's radius (p. 483) were both correct, an accounting for the most abundant of all lavas would be indeed difficult.

Can batholithic granite or the thick granitic layer of the earth's crust have originated chiefly through the metasomatic replacement of older crust-rocks by "hot granitizing fluids rich in gases" (p. 92)? One is forced to ask immediately: (1) what was the original nature of the replaced rocks; (2) where is the material removed by the metasomatic action? On page 65 we read: "migrating fluids from the depths soak into the schists [of the Finnish Pre-Cambrian shield], adding certain new ingredients and carrying away some of the old ones. As a result of this chemical interchange, the schists themselves are changed in composition, migmatites are formed, and the final product is a granitic rock. Moreover, there is growing evidence that locally the newly born granitic material became mobile and fluid. Consequently we have here a most important clue as to one—and perhaps the most important—of the ways in which granitic magmas have been generated." (p. 65.) Without any reasonable doubt the earth in Archean time was "sweating" at a

rate never even approached in later periods. Just as clearly the granitization of orthogneisses (themselves old, voluminous, metamorphosed granites), acid schists, basic schists, and quartzites took place in each of the pre-Cambrian shields. But in regions containing the post-Silurian batholiths there is no adequate evidence for similar development of their thousands of cubic miles of granite by metasomatism. In this reviewer's opinion the granite problem is obscured by failure to stress the great contrast of Archean conditions with those of later periods.

A second edition of the book might well contain fuller statements concerning the nature and mobility of the earth's silicate shell and concerning the assumption that the 1600-mile "substratum" is rich in volatile matter, which, from time to time through the ages, has been migrating toward the surface of the globe. Can either of these fundamental ideas be adequately presented in even an introduction to physical geology without reference to theory of the earth's constitution at its birth?

As it stands Professor Holmes's book is to be recommended to students both for its compact but vivid account of world facts and for its courageous effort to apply a truth seldom so concretely illustrated in other textbooks on his subject—that ultimate explanation of those facts must be sought far below the visible crust of the earth. Not the least merit of the book is the mental stimulus it gives to the professionally-inclined beginner who here learns that geology is not a cut-and-dried science and that a host of man-size, major problems of earth science await ultimate solution by those who are to enter the finest profession in the world.

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DISCUSSION.

GYMNOSOLEN NOT KNOWN FROM AUSTRALIA.

IN a recent note in the AMERICAN JOURNAL OF SCIENCE (1) Dr. P. E. Cloud, Jr. has quoted me as having informed him of the existence of a gymnsolen in probably marine strata in Australia. Since this statement is apparently due to a misunderstanding, it seems advisable to have it rectified, although the point in itself is probably of no great importance. In my letter to Doctor Cloud I referred to the find of a gymnosolen structure in marine Silurian rocks of Southampton Island, Hudson Bay, Canada, which I described some years ago (2) and to which I gave the name of *Gymnosolen canadense*. The specimen had been obtained by members of Knud Rasmussen's Fifth Thule Expedition from the western shore of Duke of York Bay, near the northern end of the island. The fauna from this general area comprised some 20 species of Silurian age, all of them represented by specimens that had been picked up loose from the surface. However, one specimen of definitely Ordovician age was among them which must have been brought to Southampton Island, probably by ice drift, from Ordovician outcrops farther north, most probably from Melville Peninsula. There is thus no final proof that *Gymnosolen canadense* occurs in place in the marine Silurian rocks of Southampton Island, but at the time when I studied these collections the nature of the rock in which the specimen was preserved and the small amount of abrasion it had suffered seemed to me to preclude the possibility of a drift origin and I included the species unreservedly among the list of Silurian fossils.

I regret that the statements in my letter to Doctor Cloud were so indistinct that this misunderstanding regarding the derivation of the specimen could have arisen.*

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*I cannot now locate Doctor Teichert's earlier letter but suspect, from the habitual clarity of his communications, that he is generously sharing the blame for an error for which I alone am responsible.

P. E. CLOUD, JR.

SCIENTIFIC INTELLIGENCE

CHEMISTRY.

Systematic Inorganic Chemistry of the Fifth and Sixth Group Nonmetallic Elements; by DON M. YOST and HORACE RUSSELL, JR. Pp. xv, 423; 78 figs., 109 tables. New York, 1944 (Prentice-Hall, Inc., $6.00).—A first glance at the outside of this book gives an entirely erroneous idea as to the character of the work: only the first three words of the title appear on the cover. The book is far more valuable because of its limited scope. It is a beautiful result of summary and criticism by research workers in their own field. The usual descriptive and qualitative character of works on inorganic chemistry is here replaced by a careful and detailed summary of the physico-chemical properties and behavior of the important group of elements treated. As a text it is suitable only for advanced undergraduate and graduate teaching. For reference by practicing chemists it will prove invaluable.

The scope of the book is sufficiently well indicated by its title.

The character of the presentation may best be indicated by a summary of the discussion of one compound. Five pages are devoted to nitrogen dioxide. The magnetic properties of the gas are stated and the assignment of the ground state of the molecule is discussed. In connection with a discussion of the structure of NO_2 the vibrational frequencies of the molecule are given. The thermodynamic properties of the solid and the liquid form the first table. The equilibrium constants and the thermodynamic functions for the association reaction are presented and discussed. A quantitative summary of the knowledge of the reversible reaction $NO_2 = NO + \frac{1}{2} O_2$ is presented largely in tabular form. The interesting problem of the rate of the association reaction forms the conclusion of the section. Here the presentation is lightened by a short description of the two experimental methods which have given results of signficant accuracy. A figure shows the course of the reaction at different temperatures.

The entire book is of the same thoroughgoing character. It is to be hoped that the remainder of the periodic table will receive similar treatment, if not at the hands of Yost and Russell, then by someone equally competent. H. C. THOMAS.

Frontiers in Chemistry. Vol. 3. Nuclear Chemistry and Theoretical Organic Chemistry. Edited by R. E. BURK and OLIVER GRUMMITT. Pp. 165; 30 figs. New York, 1945 (Interscience Pub. Inc., $3.50).—The third volume of this series (previously noticed

in this journal, Vol. 242, pp. 453-4) presents the following authors and topics:

Albert S. Keston: *Isotopes and their Application in Biochemistry.*

Hugh S. Taylor: *Application of Isotopes in Catalytic Reactions at Surfaces.*

H. R. Crane: *Techniques in Nuclear Physics.*

Leslie G. S. Brooker: *Resonance and Organic Chemistry.*

W. H. Rodebush: *The Hydrogen Bond and its Significance to Chemistry.*

The series continues as an interesting and useful addition to the literature of chemistry. HENRY C. THOMAS.

Bibliography of Solid Adsorbents; by VICTOR R. DEITZ. Pp. lxxxi, 877. Washington, 1944 (A contribution from the United States Cane Sugar Refiners and Bone Char Manufacturers and the National Bureau of Standards, $12.00. May be obtained from J. M. Brown, Revere Sugar Refinery, 333 Medford St., Charlestown, Mass.).—The subtitle of this book is "An Annotative Bibliographical Survey of the Scientific Literature on Bone Char, Activated Carbons, and other Technical Solid Adsorbents for the Years 1900 to 1942 Inclusive." The book contains a history of commercial adsorbents in relation to the sugar refining industry which is exceedingly interesting reading, and well balanced. We are constantly reminded how much we owe to early inventors not only for processes but for fundamental scientific concepts. This section (pages ix to lxxi) also pays tribute to a number of the sugar refiners and technical men prominent in the industry in this country. It is followed by a very valuable tabulation of commercial solid adsorbents used in the United States and, as far as possible, those available in foreign countries are listed.

The main body of the volume consists of the abstracts (some "six thousand and two references" are contained in the entire volume) and these are arranged in seven chapters: I. Adsorption of gases and vapors on solid adsorbents, 196 pages; II. Adsorption from solutions on solid adsorbents, 152 pages; III Thermal effects in adsorption processes, 25 pages; IV. Theories or adsorption 57 pages; V. Refining of sugars and other applications of adsorbents, 256 pages; VI. General information on adsorbents and special methods of investigation, 81 pages; VII. Preparation of carbon adsorbents, 37 pages. There then follow a list of the sources of the bibliography with key to the abbreviations of the periodicals; author index, subject index and a list of the abbreviations used in the text of the abstracts.

It is evident that the Author has done a very thorough piece of work, and he deserves the thanks of those working in the field of adsorption. This volume fills a long-felt need, one which would

probably not have been met through the efforts of a private individual. The industrial sponsors of this project are to be congratulated for making this work available. It will save so much effort for workers in all branches of the study of adsorption that it is bound to facilitate research and pay for itself over and over again This volume should be an important addition to the library of any individual or firm working with adsorption.

HAROLD G. CASSIDY.

GEOLOGY.

The Story of the Great Geologists; by CARROLL LANE FENTON and MILDRED ADAMS FENTON. Pp. xvi, 301; 26 halftones, 27 line-cuts. New York, 1945 (Doubleday, Doran and Co., $3.50).—Nontechnical writings on scientific subjects, in attractive style, serve a highly useful purpose. This latest book by the Fentons may be characterized briefly as an excellent contribution in this field, with a somewhat unfortunately worded title. Readers acquainted with the subject matter will agree that the book presents a story (or stories) of geologists who are rightly appraised as great. However, use of the definite article in the title seems to promise a reasonably full roster of those who deserve this high citation. True, in their *Foreword* the authors explain that they are considering only "men who dealt with the earth as a whole, or with features of such magnitude that they influence all geologic thought." Even under this restricted criterion, some towering figures are missing from the treatment. Germany could hardly be satisfied with only Werner and Von Buch as her "great" among geologists. Switzerland can boast broad-gauged, top-rank students of the Earth in addition to the famous Agassiz. Moreover, uninitiated readers who take the title at face value may well infer that after the middle of the nineteenth century great geologists were operative only in America.

A title can not of course be expected to indicate the full scope and content of a book. However, it should not be misleading. In this case a slight rephrasing would make the title consistent with what the book actually is—a series of biographical accounts of selected outstanding men, skillfully interwoven to outline the development of geologic thought, first in Europe and later in North America. Considerably more than half of the space is devoted to workers in this continent, and clearly the book is designed primarily for American readers. Indeed, since the scene is shifted altogether away from Europe with the migration of Louis Agassiz, a European reader may well feel that the treatment is more than a little chauvinistic.

So much attention is devoted to the title because, in the opinion

of this reviewer, the title as it stands is a liability rather than an asset to a really good and useful book. For the most part the content and the literary quality deserve high praise. Although the biographical outlines are commendably brief, details have been chosen and worded so effectively that the subjects emerge as definite personalities. Even geologists who are quite familiar with the history of the science will enjoy the fresh word-portraits and will gain from the reading a feeling of closer intimacy with some of the grand old men of geology. These sophisticated readers will also detect some errors and questionable statements. Powell's concept of the Green River as antecedent to the Uinta uplift is explained as if it were still accepted doctrine, although conclusive evidence has been published to show that the stream's course in the Uinta canyons is superposed. Powell seems to be credited (p. 247) with holding the view, before it came to Gilbert, that the Basin Ranges are bounded by great faults. The venerable concept of red color in sedimentary strata as evidence of arid climates is once again resurrected. These and other flaws will be marked by critical readers, but should not be allowed to obscure the real value of the book as a contribution to the "humanizing" of geology.

Will the intelligent layman, or the student with limited background in geologic science, find the book as entertaining and illuminating as it is to the professional geologist? This remains to be seen. Evidently the authors are aiming at a lay audience, since they include two explanatory chapters on the divisions of geologic time. Those of us who have tried to interest students in the history of the science have found that the subject has limited appeal until considerable familiarity with the principles of the science has been acquired. Let us hope that the skillful treatment and colorful style of the Fentons will help solve this educational problem.

An annotated bibliography of source literature is a valuable feature of the volume. CHESTER R. LONGWELL.

Geology for Everyman; by the late SIR ALBERT SEWARD. xi+312 pp., 8 pls., 10 figs. (Cambridge University Press, 1943. Price $3.25). —This semipopular account of geology was written by the late Sir Albert Seward, professor of botany in the University of Cambridge and distinguished authority on paleobotany. The opening chapter is a persuasive presentation of the value of geology as a hobby. On reading further it appears that the title of the book is too inclusive, for the "everyman" to whom the book is addressed is obviously a Briton; and those who are not inhabitants of the island "set in the silver sea" will miss most of its appeal. It is essentially a running account of the geology of Britain, as it can be seen during a series of journeys through the countryside.

Two features distinguish this volume from most other books on geology. The first is that it presents geologic history backward in time: the history of the Pleistocene is given first, as being nearest to us and most easily intelligible, and from this account the narrative moves successively to more and more remote periods. Because, however, geologic history, as Sir Albert himself says, is a chronicle that far transcends human history, the interest it should arouse would doubtless be increased by presenting it in the normal order. The second feature, obviously reflecting the major interest of the author, is that in the sketches of the life of the geologic periods major emphasis has been placed on the evidence of the plants, and accounts of the animals, which bulk so large in most treatments of historical geology, generally receive second place. We are tempted to call it a refreshing change! While the book cannot be said to have strong appeal to readers on this side of the Atlantic, its success in England is indicated by the fact that since the first edition was issued in 1943 two reprintings have been necessary.

ADOLPH KNOPF.

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The Meaning of Relativity; by A. Einstein Princeton, N. J, 1945 (Princeton University Press, $2.00).

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How to Solve It. A System of Thinking which can Help you Solve any Problem; by G. Polya. Princeton, N. J., 1945 (The Princeton University Press, $2.50)

Radio Direction Finders; by D. S. Bond. New York, 1944 (McGraw-Hill Book Co).

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The Story of the Great Geologists. The Story of the Earth Science through the lives of the Men who developed it from early Greece to Modern Times; by C. L. Fenton and M. A. Fenton Garden City, N. Y., 1945 (Doubleday & Doran Co., $3.50).

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Physical Methods of Organic Chemistry; by W. F. Bale, N. Bauer, et al. Volume 1. New York, 1945 (Interscience Book Co., $8.50).

ERRATUM

"SILICA IN NATURAL WATERS," by Chalmer J. Roy. Vol. 243, July, 1945, pp. 393-403.

Through a printer's error the free valence of the SiO_3 ion is shown as one instead of two throughout the paper.

American Journal of Science

NOVEMBER *1945*

MEAN LOSSES OF Na, Ca, ETC., IN ONE WEATHERING CYCLE AND POTASSIUM REMOVAL FROM THE OCEAN.

EDWARD J. CONWAY.

ABSTRACT. The significance of the logarithmic multimodal method for determining the mean losses in a weathering cycle has been further investigated by comparing with some other methods described here. The combined results from four such give 45, 67, 25 and 30 per cent losses for Na, Ca, Mg and P, while the multimodal method gives 44, 67, 20 and 39 per cent

Vogt's figure for the average P_2O_5 value of igneous rock (or at least of that fraction from which the sedimentary deposits have been formed) is shown to be too low. The true figure is in the region 0·25-0·30 g P_2O_5 per cent.

Further evidence is given in support of the view previously advanced that K was not removed from the ocean at the same rate throughout, but that the removal reached a peak in or near the late pre-Cambrian. In agreement with Hutchinson's criticism the major removal of K is considered to occur through the illites rather than through glauconite which is closely similar in structure; but there is reason to suppose that the glauconite route was dominant from the Mesozoic era onwards. Many more analyses are necessary to decide such questions.

IN a discussion on two papers (Conway, 1942, 1943) concerning the chemical evolution of the ocean, Professor Hutchinson (1944) while dealing with these works very generously—has at the same time raised some important critical points. These refer mainly to the logarithmic multimodal treatment of shale concentrations for ascertaining the losses of Na, Ca, Mg and P in one weathering cycle, and also to the hypothesis put forward for the nature of the potassium removal from the ocean, though the far reaching consequence of that removal are accepted. It is intended here to deal somewhat further with such questions, but it may be said at the outset that though the views expressed on the general nature of the K removal (Conway, 1943) appear to be supported by the additional arguments brought forward here, the special signifi-

cance of glauconite was overstressed. This agrees with Hutchinson's criticism, though the possibility of the overstressing had been indicated, the main point being the K removal as a complex silicate, with the added significance of indirect facilitation by living organisms, and the consequences resulting therefrom.

It would seem that the major rôle in the K removal must be assigned to the group of authigenic micas in argillaceous sediments, termed "illite" by Grim, Bray and Bradley (1937). With this group glauconite has close chemical relations (Hendricks and Alexander, 1939) and is micaceous in structure (Gruner, 1935).

At the same time consideration of the data (which are not numerous) suggests that after the Cambrian period the glauconite removal of K became increasingly significant and from the Mesozoic era onwards possibly the dominant route.

Also, it may be said that the data for Archaean argillaceous sediments which are likely to be of value in testing the course of K removal from the ocean, are very meagre. Conclusions based thereon must remain at present merely tentative. In this connection Hutchinson rightly stresses the need of many more analyses of the ancient argillaceous sediments.

MEAN LOSSES IN ONE WEATHERING CYCLE AND THE MULTIMODAL TREATMENT OF SHALE ANALYSES.

Prior to dealing with the points raised, some fresh material may be given bearing on the multimodal treatment of the shale analyses.

As will appear, this treatment is not essential for fixing with some degree of accuracy the mean losses in one cycle, of Na, Ca, etc., but, none the less, it contributes to the refinement of the estimates, and is in itself of much interest. Apart from the multimodal treatment, it may be said that four different methods are available for determining the *ratios* of the mean percentage losses of Na, Ca, Mg and P in one weathering cycle and three methods for fixing the absolute mean value of the Na percentage loss and hence of the others.

The results so determined will be compared with that from the multimodal treatment, before dealing with the criticism of this procedure. The three methods for determining the mean absolute Na loss in one cycle are first described.

The mean absolute Na Loss in one cycle.

1) In the first method, the mean value is taken from Merril's observations (1897) as already considered (Conway, 1942) and is found to be 47 per cent.

2) The mean Na loss may be also deduced from the analyses of 78 shales listed by Clarke (1924) (weighted mean of composite analyses of 51 Palaeozoic and 27 Mesozoic and Cenozoic shales) in conjunction with the data for "igneous" river water (Conway, 1942).

In the shales the Ca and Mg are present both as carbonates and as silicates. It is necessary at the outset to deduct from the shale analyses the amounts of CaO and MgO present as carbonates. These may be determined by allowing for each gramme of CO_2 in the shales over and above the amount in igneous rock (i.e. $2\ 63-0.10\% = 2.53$ g. CO_2) 1.027 g. CaO and 0.19 g. MgO per 100 g. rock, as carbonate, since this is the mean proportion of CaO and MgO associated with CO_2 in limestone.

The CaO value remaining then is 0.51 g./100 g. and with this is associated 1.30 g. Na_2O. It will be assumed that one g. of igneous rock forms in the average 1 g. of sedimentary terrigenous rock (Conway, 1942) taking the mean of the silica and alumina calculations. Since the shales form 0.8 of the whole, then if all the remaining silicates were concentrated therein we could multiply the analyses by 0.8 to obtain the amount present in the sedimentary rock; but the silicates are not altogether concentrated in the shales and 0.9 is a better factor. This appears from a study of the analytical data, and probably gives the correct value to within a few per cent. The Na_2O and CaO (corrected) concentrations in the shales being 1.30 and 0.51 g./100 g. and 3.84 and 5.08 in the igneous rock we may write

$$3.84\,(1-x_1)^y = 0\,9 \times 1.30 \quad \ldots\ldots\ldots\ldots \quad \ldots 1$$
$$5.08\,(1-x_2)^y = 0.9 \times 0.51 \quad \ldots\ldots\ldots\ldots \quad \ldots 2$$

where x_1 and x_2 are the ratios lost in a weathering cycle, and y the mean number of cycles.

Now from the "rain-corrected" values of "igneous" river water the relation of x_1 to x_2 may be determined by the relative concentrations of Na and Ca present divided by their concentrations in the igneous rock, or 2 8/2.85 : 5.8/3.63 or 1 : 1.63. Inserting $1.63x_1$ for x_2 in equation 2, we may solve for x_1 as

0.39 or 39 per cent of the Na is removed in one cycle, and y appears as 2.4.

3) A study of the composition of "sedimentary" river water gives a third method. In the mean sedimentary rock about 90 per cent of the Ca is present as carbonate which may be supposed to go entirely into solution. From the remaining 10 per cent there is also lost a high proportion, so that it follows that with little error we could assume that all the Ca in the sedimentary rock goes into solution and hence calculate the proportion of weathered rock to unit volume of river water. From Table 12 of the paper on Mean Geochemical Data, etc. (Conway, 1942), the Ca content of the "sedimentary" water is 37.5 p.p.m. so that the rock involved is $37.5/3.89 \times 100$ or 964 p.p.m. Since this figure will be a few per cent below the true figure, approximately 1000 p.p.m. of sedimentary rock may be assumed. This will contain 8.2 p.p.m. of Na, and since the Na content of the "rain-corrected" sedimentary water is 4.1, 50 per cent of the rock Na has been dissolved out. Combining these three values—47, 39 and 50 per cent we obtain a mean of 45 per cent which will be used in the subsequent calculations.

The *relative* losses of Na, Ca, etc., will now be considered.

Relative losses of Na, Ca, etc.

Two such methods have been already described (Conway, 1942). They are the means from Merril's results, and from the data of "igneous" river water. They are listed in Table I with the Na figure adjusted to 45 per cent of the mean

TABLE I.

Percentage of igneous rock constituents lost in one weathering cycle.

Substance	From Merril's data	From "igneous" river data	From composite shale analyses	From slopes of "coequal" lines (using log values)
Na	(45)	(45)	(45)	(45)
Ca	57	73	70	64
Mg	49	20	29	26
P	33	(31)	29	30
K	33	29	..	.

The P is included under "igneous" river data though it was determined—owing to lack of data—from the "sedimentary" river water.

K is omitted from the last two columns owing to the high degree of return to the shales, which cannot be allowed for like Ca and Mg in the composite analyses.

figure determined above. To the river estimates is now added the phosphate figure. In his collection of river data (Clarke 1924) lists 22 phosphate analyses. This number is comparatively small, but may be used for the present purpose. Of the 22 if we take the 12 figures with the highest salinities, the median salinity is 175 or close to that for typical "sedimentary" water, and the phosphate figure (as P_2O_5) is 0.46 p.p.m. From the calculation above, 1000 parts of rock may be allowed per million of water, and containing 1.50 parts of P_2O_5, so that $(0.46/1.5) \times 100$ or 31 per cent of the phosphate is dissolved out.

3) As in equation 1 we may write for the 78 shales

$$3\ 84\ (1-x)^y = 0.9 \times 1.30 \quad \ldots\ldots \quad 3$$

Here x may be taken as 0.45 and then y is approximately 2.0. From similar equations for CaO, MgO and P_2O_5 taking the CaO and MgO as silicates with the carbonate values subtracted (as described above, leaving 0.51 and 1.96 g. per cent) and the igneous rock values of 5.08, 3.49 and 0.299 respectively, the value for x become 70, 29 and 29 per cent respectively.

4) In a fourth method the relative losses may be determined from the slopes of the lines of best fit through the logs of the values of CaO, MgO, etc., against the logs of the corresponding Na_2O content of single shale samples. Here 39 shales from Clarke's data (1904) are considered as in the multimodal treatment. (These shales were listed in **Bulletin 228, U. S.** Geol. Survey, weathered or altered specimens being omitted, as also those shales listed as calcareous or which were considered from the description as exceptional. There remained, pp. 337-339, A-K; pp. 340-341, A-E; p. 342, A and B; p. 343, D; p. 344, A-C (Michigan); p. 345, A-C; p. 346, A; p. 347, A-E; p. 348, A; p. 349, A, B, D and E; p. 350, F, H, J.)

For CaO and MgO, it was thought better to omit altogether those samples having a carbon dioxide content greater than 0.2 g./100 g., rather than to correct for it as in the composite analyses of shales, since for some shales when this correction is applied a slightly negative value results for the CaO. This is due either to the analyses themselves being somewhat in error when a very low CaO content may appear on correction as a negative value, or to some CO_2 being associated with iron. In this way 20 shale analyses were available for the CaO and MgO investigation.

The question arises, however, as to the most suitable equation for the line of best fit. With ordinary statistical regression lines, if one of the variables is known to be dependent on, and is more or less closely determined as a linear function of the other variable, then the regression line of the dependent on the independent variable is significant. But when the variables are in no degree determined by each other, one regression is not more significant than the other. They merely fulfil the mathematical condition, that the sum of the squares of all the deviations from the line, as measured along the ordinate on the one hand, or along the abscissa on the other, should be a minimum. But where there is no determining relation between the variables there is no valid reason for measuring deviations parallel to one or other axis, but rather as the perpendicular distances of the points from the line. In this way we get a single line, which for lack of a better name, will be here termed the *coequal* line of best fit, implying that neither variable is considered to be dependent on the other. The slope is given by the relation—

$$b = -\frac{(\sigma^2_x - \sigma^2_y)}{2r\sigma_x\sigma_y} + \frac{1}{2}\sqrt{\left(\frac{\sigma^2_x - \sigma^2_y}{r\sigma_x\sigma_y}\right)^2 + 4} \quad \ldots\ldots\ldots 4$$

In this 'r' is the correlation coefficient, and σ_x, σ_y the standard deviations. When Y is substituted for X the resulting expression becomes the reciprocal of the first.

The statistical data for finding the coequal lines of best fit are given in Table II, and when it is assumed that 45 per cent

TABLE II.

Correlations of log of the CaO content, etc., with log of the Na_2O content using the group of 39 shales (Clarke, 1904) commented on in the text. In the last column is given the slope of the coequal lines of best fit (equation 4).

Variables	No. of obs.	Standard deviations		Means		Correlations	Slopes of "coequal" lines
log (CaO%; log (Na_2O%)	20	0.41	0 33	–0.285	–0.04	+0 38	1.71
log (MgO%); log (Na_2O%)	20	0.24	0.33	0.39	–0.04	+0.44	0.50
log (P_2O_5%); log (Na_2O%)	34	0.25	0.32	–0 97	–0 02	+0.46	0 60

of the Na_2O is lost in a cycle, then from the slopes it would appear that 64 per cent of CaO, 26 per cent of MgO and 30 per cent of P_2O_5 are lost concurrently.

The means from the four methods (discarding the magnesium value from Merril's data—which is clearly aberrant) may then be compared with the results of the multimodal method.

	Means of the 4 methods	Results of the multimodal method (2)
Na	45%	44%
Ca	67	67
Mg	25	20
P	30	39

This agreement is scarcely fortuitous.

While the percentage losses of Na and Ca agree very well, the Mg and P values are also of a similar order in the two lists. It is true that occasionally the data are relatively meagre, but the convergence of the mean results from different methods gives some confidence in the figures for the mean losses in one weathering cycle, and the significance of the agreement with the multimodal treatment.

Hutchinson's criticism may now be considered. He points out firstly that the Na_2O content of 25 massed Mesozoic and Cenozoic shales (Clarke, 1924, p. 552) is 1.80 per cent while that of 51 Palaeozoic shales is 1.20 per cent, which would seem to indicate that later shales were somewhat richer than earlier but the explanation of this may well be that for a small group of 25 samples the average number of cycles they have undergone may be less than for a group taken at an earlier period, especially when the earlier period differs in time by only a small fraction of the oceanic age (and this latter point is in fact indicated by Hutchinson). Hutchinson then raises the question of phosphate and the nature of its loss from the sedimentary rock, but if the fact of such loss be granted it does not seem to matter how it happened for the immediate problems discussed. The indication given in the criticism that it may have been deflected into the inacessible sediments of the permanent oceanic basins is doubtless the correct one, and what the writer had in mind. It may be noted that owing to the comparatively low level of the P_2O_5 content of rock, the deposition of calcium phosphate in the skeletons of animals into the non-terrigenous pelagic sediments—constituting by far the greater fraction of the whole ocean floor—may be expected to account for very appreciable relative losses in the sedimentary rock of the present land surface. How numerous the skeletal remains of larger animals can be in the pelagic sediments is illustrated by the fact referred to by Twenhofel (1939, p. 127) that in a single dredge made by the "Challenger" in the central Pacific, there were 1500 shark teeth and about 50 ear bones of whales.

Here the most important point raised by Hutchinson is that if Vogt's figure (1931) for the mean P_2O_5 content of igneous rock is correct, then there appears to have been almost no loss from the sedimentary rock. The figure for igneous rock as given by Vogt is "probably about 0.17-0.18" and for the totality of sedimentary rocks, recalculated without CO_2 and H_2O it is given as about 0.165. The mean loss of P_2O_5 would then have been about 6 per cent only. Consequently if the phosphate appears to have been lost in a somewhat similar degree to Na, according to the multimodal treatment, this latter would seem of doubtful value. The following arguments may, however, be advanced against the validity of Vogt's P_2O_5 figure for igneous rock.

a) For the 34 shales examined (of Clarke's series, 1904) the correlation of P_2O_5 with Na_2O content is +0.59 or +0.46 for the logarithmic values. This means that high sodium values are associated with high phosphate and vice versa, or that if Na is lost from the rock—which occurs extensively—so also is phosphate. This correlation of +0.59 may be compared with that of −0.02 for the Na_2O and P_2O_5 content of *igneous* rock as determined from the large number of data in Washington's superior (and complete) analyses (1917) putting "traces" of phosphate in the lowest class division (0.00-0.05 g. per cent). This is practically a correlation of independence, the slight negative value being due to the association of the highest P_2O_5 figures with low Na_2O values.

Since the Na_2O and P_2O_5 of the sedimentary rock are both present in the shales to the extent of approximately 0.9 of the whole, we can regard the coequal line of best fit through the points as giving the relation of Na_2O to P_2O_5 in the whole sedimentary rock. When the Na_2O value on this line is equal to that of the mean igneous rock we should also obtain the mean P_2O_5 value. It is found to be 0.27 g./100 g.

From a similar line (line B) through the logarithmic values (Fig. 1) the P_2O_5 figure corresponding to an Na_2O value of 3.89 g./100 g. is 0.25 g./100 g. (The dotted lines D and E proceed from 3.89 and 0.30 per cent.) It will be seen that the logarithmic values for 51 Palaeozoic and 27 Mesozoic and Cenozoic composite shale analyses are somewhat above the line B and correspond to a P_2O_5 value of 0.30 g./100 g. when the Na_2O per cent is 3.89 g./100 g. (as given by line C).

b) Vogt's figures would indicate that only a negligibly small proportion of the phosphate deriving from the weathering of igneous rock was lost in the pelagic and non-terrigenous sediments. This is improbable, as discussed above.

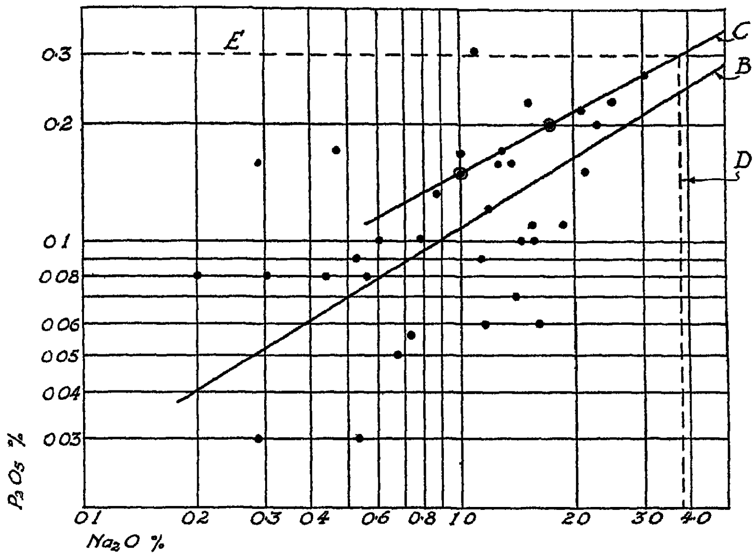

Fig. 1. The Na_2O and P_2O_5 content of shales plotted on double logarithmic paper. The dots are for the 39 shales of Clarke's group commented on in the text (34 of which have both substances analysed)

The large circles represent 51 Palaeozoic and 27 Mesozoic shales (composite analyses). Analyses given by Clarke (1924).

The line B is the "coequal" line of best fit (see text). Line C is drawn directly through the large circles. The dotted lines E and D correspond to the mean P_2O_5 and Na_2O content of igneous rock as given by Clarke (1924; from Washington's collection, 1917).

If Vogt's figure is then incorrect, the question arises as to how an error of estimate enters his calculations. The following points may be noted.

c) If the nature of the frequency distribution curve of P_2O_5 be considered, taking all the data given by Washington (1917) as superior (and complete) analyses, and placing "traces" in the lowest class division, we get the curve shown in Fig. 2. A similar curve is given if the analyses be confined to granites only The distribution of Na_2O, for example, is much different as shown in Fig. 2. From such phosphate curves or their corresponding data, it is certain that the arithmetical

mean will be higher than the median or central figure, but if we had the true distribution it is only the arithmetical mean that is here significant. In his calculation Vogt uses half the arithmetical mean plus the median, and though a certain compensation in this way be affected against the undue inclusion

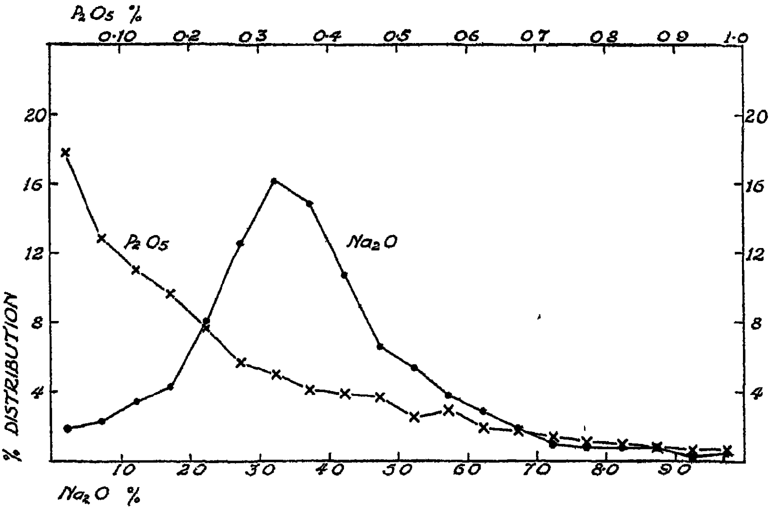

Fig. 2. Frequency distribution of P_2O_5 and Na_2O analyses of igneous rocks, from Washington's group of Superior and Complete analyses (1917). Only those Na_2O figures are considered which have associated phosphate analyses mentioned either numerically or as traces. The points are placed midway in the class intervals.

in the whole distribution of rare rocks containing much P_2O_5 yet Vogt used the method throughout, as, for example, in his calculations of the average P_2O_5 in the granites, gabbros, basalts, etc. For such distributions this inevitably introduces a tendency towards a figure lower than the true value.

d) In the calculation of the probable average of the P_2O_5 value in igneous rocks, Vogt deals only with the plutonics, ignoring the dikes and flows, though giving reasons for this. He points out that the dikes have relatively very small dimensions and with regard to the cubic mass the flows on the whole are quite subordinate compared with the plutonics, and have a much smaller vertical depth. None the less the flows are relatively much richer in P_2O_5 than the plutonics (an average of 0.46 P_2O_5 in the basalts, for example, compared with 0.29 for the corresponding gabbros) and may contribute more to the

sedimentary rock than appears from a comparison of the vertical depths studied.

However this may be, the evidence indicates that Vogt's figure, in so far as it applies to the mother rock of the analysed shales, is relatively too low. It is true that Goldschmidt (1937) in a notable paper agrees with the P_2O_5 figure of Vogt, but for this he brings no fresh evidence.

The removal of potassium from the ocean.

It was pointed out (Conway, 1943) that the removal of K ions in quantity from the ocean necessarily affects the concentration of Ca, Mg, etc. The view was also put forward that until the development of organic life in relatively large volume the free K concentration rose and then fell, that its removal was due to the formation of glauconite, but "it would seem very probable that a more dispersed or earthy form of glauconite may be formed apart from the granular mineral in shells, a peculiarity of which is its growth from the original nidus formed at the site of the organic material. Quantitative studies of such processes are lacking, but the important point here is the manner of the removal of potassium by reactions originated by decaying organic matter, and this method may be assumed to predominate."

From recent work on the clays (reviewed by Grim, 1939; 1942) the diffuse or earthy glauconite above considered may now be referred to as "illite." The name was given by Grim, Bray and Bradley (1937) to cover the authigenic micas in argillaceous sediments (Endell, Hofmann and Maegdefrau, 1935; Grim et al., 1937; Maegdefrau and Hofmann, 1937) and these appear to be very similar in structure to glauconite. According to Grim (1942) illite is present in many soils, but usually as a remnant of the composition of the parent rock, and in most shales that have been studied it is the dominant clay mineral.

The magnitude of the K removal from the ocean may be calculated as follows. Examination of the mean data for "rain-corrected" river water shows that potassium is 0.6 times the Na concentration in "igneous water" and 0.76 times that in the total river water. Throughout the oceanic age it may be taken in the average as about 0.7 the Na concentration (reckoning K and Na figures as p.p.m.), though the factor for the first period is near to 0.6, and in the later phases to 0.8. Since approxi-

mately 141 × 1.09 Gg. of Na (1 Gg. = 10^{20} g. Conway, 1942) have been set free from the igneous rock (1.09 being the factor taking account of the NaCl in the pores of the sediments and as rock salt, and 141 Gg. representing the total in the ocean water) it follows that about 108 Gg. of free K have been brought by the rivers to the ocean, and allowing for the relatively small amount of free K present therein, about 100 Gg. of K in round numbers have been removed therefrom, and fixed as silicates; probably in much the greater part as illite, also as glauconite, with which it is closely related, and possibly also in relatively small amounts as authigenic orthoclase.

An hypothesis of Rutherford (1936) may be here briefly considered. From the fact that most of the potash deposits formed by evaporation of saline waters appear to be of a geological age younger than the Carboniferous, he has supposed that K was added to the ocean in appreciable amounts only since the formation of land vegetation on a large scale, the first notable increase in oceanic K occurring in the Carboniferous. Rutherford concludes that "areas of present day tropical vegetation may be contributing materially to the potash content of the sea, but a subsequent period of dessication causing the precipitation of salts is necessary to determine such a possible effect." Such contributions can, however, be determined by examining the river data. The Amazon basin may be taken as an area of luxuriant tropical vegetation, Reade (1903) estimates the denudation factor as 50 tons of river solutes per sq. mile per annum and Clarke (1924, p. 117) puts it at 53 tons, so that from Frankland's analyses (as cited by Reade, 1903) the K removal is 53×2.31/100 or 1.2 tons/sq. mile/year. Similarly the average for Europe and North America is 2.7 and 1.4 tons K/sq. mile/year. Also if Chelu's figure (as quoted by Clarke, 1924, p. 118) of 16 tons for the denudation figure of the Nile basin be taken as approximately correct, and the average value of K in the Nile water be assessed from the figures listed by Clarke (1924) the K from the Nile basin is 0.8 ton K/sq. mile/year. The total average of K removal from the tropical basins in South America and Equatorial Africa is thus 1.0 ton/sq. mile/year and for the temperature regions of Europe and North America it is 2.0. These figures appear to disprove Rutherford's hypothesis that prolific vegetation markedly increases the load of free K ions to the sea and are against the view that, prior to the

initiation of large scale vegetation no free K ions were entering the ocean. It will be assumed therefore that the present river data are an indication of what has always occurred with respect to the average ratios of Na, K, Ca and Mg entrance into the ocean.

As shown (Conway, 1942) the K in "igneous" river water represents a relative loss of 26 per cent of the K in the rock, which is not far from the rough average of 35 per cent from Merril's direct observations on igneous rocks. In "sedimentary" river water the free K is 15 per cent of the K in the rock and the fall in the percentage loss we may ascribe either to a less rapid weathering of illite so as to liberate free K or a greater retention of the K liberated in the corresponding sediment brought down by the river water.

From the inorganic content of "sedimentary" river water and the adsorption relations of the various ions, such relative retention cannot be explained by simple adsorption but rather by the fixation of K between the unit layers of the space lattice. This river K in solution is in virtual equilibrium with the corresponding inorganic sediment (implying also the clays through which the water has soaked) and at a given moment shows in the mean the relations of a cycle of denudation.

For the disappearance of the 100 Gg. of K from the ocean the following three views may be considered.

a) The K has been removed at the same rate throughout.

b) Its removal has been increased by the greater development of organic life, presumably occurring with the advance of pre-Cambrian time.

c) Its removal has almost altogether depended on the presence of organic life with cellular development similar to that now observed but reaching relatively large volume only at some time in the late pre-Cambrian period.

In a previous paper, the 'a' and 'c' hypotheses have been developed ('c' more than 'a'). They represent the limits over which the question can be treated, though the 'c' hypothesis was then taken as representing the more probable course of events.

If the amount of glauconite present in all the present marine and continental sediments is quantitatively significant the rejection of 'a' would in any case seem called for, since the formation of glauconite appears to be much facilitated by organic matter. Galiher (1936, 1939) showed that glauconite can be formed

by the diagenesis of biotite, but this is only a part explanation of its occurrence since it appears abundantly in many widespread formations which show no evidence of the influx of mica (Takahashi, 1939). From Yagi and Takahashi's work it now appears that though glauconite is formed by diagenesis the parent substance can vary greatly and in the process of formation, iron, potash and magnesia are absorbed from the millieu. To account for 100 Gg. of K would require 1500 Gg. of the granular mineral (assuming an average of 6.6 per cent K, as from the formula of Hendricks and Ross 1941) and thus constitute upwards of 20 per cent of the entire sedimentary rock—a calculation agreeing largely with that of Hutchinson, and from which it is clear that the hypothesis of removal by glauconite alone must be discarded and the major fraction assigned to illite (or the authigenic micas). Illite, with approximately 5 per cent K should then account for nearly 27 per cent of the sedimentary rock, which would agree with the order of figure described by Grim (1939).

The following questions remain then for consideration—

1) *Is the marine formation of illite facilitated like glauconite by the presence of organic matter produced by living organisms or representing their dead cells; and—*
2) *When did such organic matter appear in quantity?*

The following points may be made in support of the facilitation by organic matter.

a) There appears to be a close chemical relation between glauconite and the authigenic micas or illite as shown by Maegdefrau and Hofmann (1937) and Hendricks and Alexander. Gruner (1935) from his X-ray studies concludes that glauconite is a mica in structure. This points to similar chemical conditions of formation.

b) The fact that K appears to have been over-restored to the shales in Cambrian time and probably for some fraction of pre-Cambrian time (as dealt with below) is well interpreted in accordance with the curves for the oceanic K (Conway, 1943), which have been based on the hypothesis that up to some time prior to the Cambrian the K concentration of the ocean was increasing, but with the large scale organic development probably then ensuing it fell, K for a period being over-restored to the shales.

Before considering the evidence for this latter, the mean K in the shales representing no and full return of K may be calculated. From igneous rock 26 per cent (mean value) of its K is lost in a cycle of denudation (as shown by present river analyses), and a total concentration of 3.18 $\times$ 0.74 g./100 g. in sedimentary rock should appear if there was no K return. As the shales constitute 80 per cent of the terrigenous sediments and contain approximately 0.9 of the whole K of the sedimentary rock, then the K_2O concentration of the shale formed after the one cycle should be 2.65 per cent and the corresponding Na_2O figure would be 2.37 per cent the K_2O being 1.12 times the Na_2O per cent. After a second cycle the K_2O figure would be 1.96 and the Na_2O 1.30, the ratio being 1.51. It would appear also worth considering what present shale formation should contain if none of the "sedimentary" K of river water was being restored. Such river water contains 3.3 p.p.m. of K, associated with the denudation of 980 p.p.m. of sedimentary rock (Conway, 1942) which contains in all 27.4 parts of K_2O. It may be calculated therefore that the shale produced from such rock should have an approximate K_2O concentration of 2.40 per cent if the river K was not restored.

On the other hand if K of the igneous rock were fully restored to the shale in one weathering cycle, then the total sedimentary rock should have a concentration of 3.13 per cent K_2O, or 3.50 per cent in the shales. Such a figure would leave out of account the fixation of K in glauconitic formations; and must be regarded as an upper limit.

Comparing these figures with the actual analyses, the composite figure for 51 Palaeozoic shales (Clarke, 1942) is 3.60 per cent K_2O and the mean figure for 17 separate analyses of Cambrian shales (Clarke, 1904) is 3.97 $\pm$ 0.15 (s.d. of mean). The composite analyses of 27 Mesozoic and Cenozoic shales (Clarke, 1924) gives 2.60 per cent K_2O. The Cambrian shale analyses show an over-return of K_2O, while the Mesozoic and Cenozoic shales show little or no return of the river K at the time of their formation. Further support for this appears on plotting the K_2O distribution for the 39 separate shales already referred to above in Clarke's assembly of sedimentary data (1904). In Fig. 3 (A.B) the separation is made into Cambrian and other shales. It will be seen that there is a higher K_2O distribution for the Cambrian samples. Additional light appears to be thrown on the matter when the K_2O values

in these distributions are plotted against their corresponding Na_2O figures, as in Fig. 3 (C & D). It will be seen that for shales other than Cambrian (C) (data from Clarke, 1904) there is a definite inverse relation of K_2O and Na_2O (the correlation is -0.6). A curve is drawn through the means for 0.5 per cent Na_2O intervals, the mean K_2O value for the lowest Na_2O concentrations lying a little over 4.0 per cent. Also it is of interest that on this curve the K_2O figure corresponding to an Na_2O value of 2.37 per cent (or that to be expected from one cycle of weathering) is 2.3 or slightly less even than the expected 2.6 per cent with no return of K (as calculated above). For the Cambrian shales in Fig. 3 (D) there are no high Na_2O

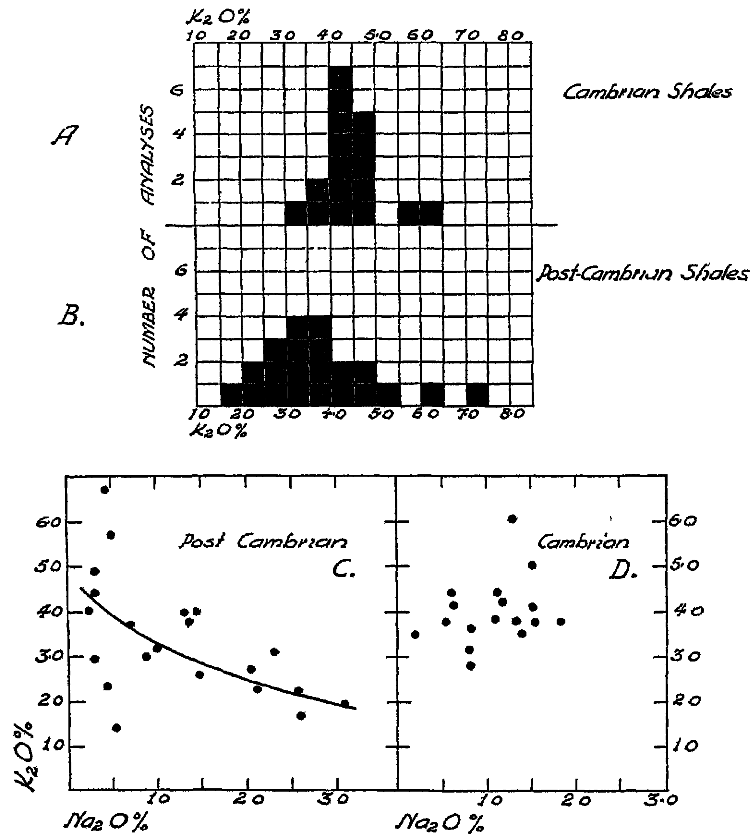

Fig 3. A and B—distribution of K_2O analyses of shales, Cambrian and post-Cambrian (from the group of 39 as referred to in the text).

C and D—the K_2O content plotted against the corresponding Na_2O content.

values and the mean around 1.5 per cent Na_2O is over 4.0 per cent. There appears some tendency for the K_2O concentration to fall at lower Na_2O levels.

All this appears to fit in with the view that in Cambrian time, with extension back into pre-Cambrian, K_2O was being over-returned to the shales subsequent to a period in which the return was either not made or poorly made, and that once the K_2O was replaced in the rock it was not readily lost when elevated later on the land surface. A Mesozoic or Cenozoic shale with high Na_2O, indicating one cycle of deposition shows also little or no K return, whereas with low Na_2O it shows a tendency to a high concentration of K_2O since this has been returned or over-returned in an earlier period.

The lack of K return to the shales in the more recent eras (so far as may be judged from the relatively few figures) suggests the diversion then of much of the river K into granular glauconite rather than into illite. Glauconite may thus play an increasing and finally dominant rôle in the marine fixation of potassium.

c) An argument in connection with Red Clay seems worth considering here. Red Clay constitutes perhaps one-third to one-half or more of the whole sedimentary deposits. It appears to be made up in considerable part of volcanic material, with lower K than igneous rock, and this would seem relatively little weathered. It represents a high fraction of the total clay with relatively low contribution of K to the ocean and thence to the sedimentary deposits. If K has been fixed therein from the earliest times it would seem that an appreciable fraction of the K from the weathered igneous rock would be prevented from returning to the shales. It is difficult to believe therefore that in Cambrian time such a process could be occurring when the K was being over-returned to the terrigenous sediments. The matter cannot be satisfactorily tested from present Red Clay analyses, because not only is the true source material uncertain but only the superficial layers have been examined and there is also some doubt about the mean Na content of such samples (as discussed by Kuenen, 1941).

In this conjunction it may be noted that Correns (1939) has emphasized the low molecular ratios of K_2O to Na_2O (0 2 – 0.8)

for the Meteor samples of Red Clay, and quotes in support the careful analyses of Harrison and Jukes-Brown (1895) on some Challenger samples in support. The average of 51 analyses of Red Clay by Clarke and Steiger (Clarke, 1924) gives a K_2O to Na_2O ratio of 0.9. If we take the ratio for the volcanic source material as computed by Kuenen (1941) we obtain 0.42, and this would therefore be the expected ratio if there were little weathering. The findings of Correns would thus receive quite a simple explanation without recourse to base exchange and special adsorption hypotheses. The following statement of Correns (1939) the present writer finds especially strange. "Fossil clays very rarely exhibit this predominance of Na. After they pass from their environment they come into the influence of terrestrial solutions which are rich in K." As it stands this would appear to imply that terrigenous sediments show similar $K_2O : Na_2O$ ratios to Red Clay, and that when elevated on the land surface they are in general exposed to solutions richer in K than the ocean, which is contrary to the available evidence.

If K was not being fixed appreciably in Red Clay as in the terrigenous or near shore sediments of Cambrian time, the reason may be attributed to the presence of much larger amounts of organic matter in the latter, coupled with a relatively high oceanic K content.

d) The occurrence of a relatively alkaline pre-Cambrian ocean with low Ca content as postulated by Daly (1909, 1910) would receive an explanation in K removal from the ocean being dependent on the large scale appearance of organic matter occurring presumably in the late pre-Cambrian period. The associated release of acid then would decrease the alkalinity and increase the Ca content as already discussed (Conway, 1943).

If in regions the local removal of K is sufficiently rapid, as we may conceive it to be under certain conditions of glauconite formation in foraminiferal tests, the water may become sufficiently acid to be aggressive to calcareous cement and explain such observations as those of Oakley (1943).

While such arguments and evidence support the view that K was not removed from the ocean at the same rate throughout, but was removed but little at first and had later a peak period (in late pre-Cambrian extending perhaps into Cambrian time).

Hutchinson refers to Eskola's figures for Archaean argillaceous sediments (1932) being consistent with the uniformitarian view that K removal started as soon as the ocean devel-

oped, though commenting at the same time on the meagreness of the data. It is true that such results are not inconsistent with this view, but on examination it will be found that Eskola has listed five such analyses of varved mica-schist (samples 1, 2, 3, 4, 7 of his table), and refers the high potash in two of the samples (Nos. 3 and 4) to an approximately syenitic composition of the original igneous rock. This would leave only three for consideration and but two show Na sufficiently weathered. One of these may be advanced for and one against the hypothesis that K was not being returned to the Archaean sediments. If we include as well the analyses of calcareous concretions in the mica-schist (Nos. 8 and 9, the CaO content of which does not at the same time exceed about 13 per cent) these would show no K return. Clearly, however, the data are altogether too meagre.

Organic life in the Archaean ocean.

For the presence of organic life in Archaean time, there is the evidence of finely disseminated carbon, in the form of graphite in schists of argillaceous composition. The amount found by Eskola was 0.31 per cent (1932). Pettijohn (1943) refers to Grout's analyses of carbon-bearing slates and graywackes of the Canadian Shield, in which 1.7-1.9 per cent of "organic matter" was found. The following statement of Eskola is of interest. "The Finnish geologists are well aware that not all occurrences of graphite are of a primary sedimentary origin. Numerous occurrences, some of them connected with sulphide deposits, have been interpreted as products of metasomatism (c.f. Laitakari, 1925). It is the occurrence of primary sedimentary structures, observed at all different stages of metamorphism, even in the older Archaean that has led the investigators to the conclusion that the carbon-bearing schists also comprise bituminous shales formed in the same way as recent bituminous muds in deep coloured basins in which hydrogen sulphide results from the decay of organic substances in the absence of oxygen."

Firstly, it may be pointed out that the *average* organic carbon in Palaeozoic shales is 0.9 per cent while the C in the sample of *carbon-bearing* Archaean schist is given as 0.3 per cent. Apart from this, in the above statement an atmospheric oxygen content of a similar order to present conditions is assumed. Such a conclusion is questionable, and it is possible that in the

Archaean or early Archaean the atmosphere may have been predominantly reducing rather than oxidising. Some evidence for this may be deduced from the iron analyses, though of its nature it is merely tentative owing to the comparatively meagre chemical data for Archaean argillaceous sediments, as well as exact studies of the metamorphism compared with similar but later formations. Thus for the mica-schists and phyllites as given by Eskola (1932) the mean ferric iron content as a ratio of the whole is 0.17. For 6 graywackes as listed by Pettijohn (1943) the mean is 0.18. For 30 later graywackes (Tyrell, 1933) the ratio is 0.47 and for 6 later mica-schists (Clarke, 1924) the mean is 0.27. It may be added that the mean figure for Cambrian and post-Cambrian shale is 0.60.

In the metamorphism of shales to slates, phyllites and finally mica-schist, there is a progressive reduction of the iron but in the Archaean schists and phyllites this process appears to have gone much farther. Also the difference between the ferric content of the Archaean and later graywackes is striking. Yet from Pettijohn's description it may be gathered that there is no significant metamorphic difference between these early and late graywackes, and the varved schists described by Eskola show only a low grade metamorphism or diagenesis apparently not greater than for such schists in general. Why then is there a considerably lower ferric iron content? It may be suggested that the atmospheric conditions prevailing at their formation were of a kind which assisted the change of ferric to ferrous iron, and if so the atmosphere must have been almost entirely free of oxygen. This may be shown as follows.

The characteristic potentials of the oxygen and the iron system at pH = 0 are 1.3 and 0.75, but owing to hydrate formation the iron potentials are not given for high pH values. Yet from the fact that for Red Clay the ferric to ferrous ratio is 9 : 1 and that some of the ferrous iron may be expected to be protected within space lattices, the differences between the E values for the two systems in such marine conditions must be at least about 0.06 volt, which, though a very rough consideration is all that is necessary for the following deduction. The general redox equation of the oxygen system may be written

$$E_h = E_0 + 0.015 \log P - 0.06\text{pH}$$

where E_h is the potential against the normal hydrogen electrode. At a fixed pH (which we may take as the present marine pH)

to lower E_h by 0.06 by changing the oxygen pressure from P_1 to P_2 gives the relation—

$$4.0 = \log P_1/P_2$$

or, P_1 is then 10,000 times as great as P_2.

Even if the atmosphere were practically oxygen free, this does not preclude the existence of organic life, but since the anaerobic life is known to be very inefficient from the standpoint of energetics, it would render improbable any large volume comparable to present conditions.

A further point which may be of much importance in relation to the fixation of K, is the fact that multicellular animals (which presumably did not develop until the late pre-Cambrian) that are buried in the soft muds, or burrow through them, or again are inclosed in shells which inhibit their contents in solution from quickly diffusing away after death, may present then, for some appreciable time, a zone of relatively high K concentration. This with present marine conditions would amount to upwards of 40 times the oceanic K.

Consideration of Noll's synthesis work (1936) at raised temperatures suggests that such a condition would be a favorable one for the formation of illite from montmorillonite, the ease of which conversion is pointed out by Grim (1939) who, referring also to Noll's work, considers the pH of the environment and the character of the alkali or alkali earth present as likely controlling factors.

While such arguments as given above may be advanced in support of the general course of the oceanic potassium concentration developed in a previous paper (Conway, 1943), it is true that the exact position of the potassium peak in the pre-Cambrian was rather arbitrarily chosen. Described as the provisional peak of the curve, it was considered desirable none the less to present it so as a possible aid for subsequent and better documented advances. The point selected was the third quarter of pre-Cambrian time, it being assumed that for the first half the oceanic sediments were relatively free of organic life, which began to develop largely in the second half, the peak of the K curve occurring about mid-way therein.

It is reasonable, anyhow, to suppose that for some fraction of pre-Cambrian time the oceanic sediments were free from the debris of dead cells, that the accumulation occurred gradually,

and that if, as supported by such reasoning as above this organic matter was operative in fixing potassium in the shales (when combined at least with a high oceanic K), then a fall after an initial rise with the appearance of a peak on the curve of oceanic K concentration must have occurred. This would have happened some time before the Cambrian shales were laid down, as is evident from the over-return of K to these formations.

It will appear, however, that to settle such large questions of marine geochemistry many more analyses of argillaceous sediments of various ages are necessary, and if the present writer's work has called attention to theoretical advances that may well follow such study, he feels it will have been amply justified.

I wish to acknowledge my indebtedness to Professor Hutchinson and the American Society of Petroleum Geologists for their kindness in sending me copies of literature which was here unavailable.

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A KINETIC THEORY ON THE ORIGIN OF OROGENIC FORCES.

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ABSTRACT. Disturbance of the earth's axis of gyration is considered as a possible cause of crustal deformation. It is shown that tilting of this axis by 10′, or a small translation of the axis, would be quantitatively sufficient for the results displayed in the great orogenic belts. As the initiating cause, leveling of great highlands by erosion, with transfer of the debris through moderate distances, would disturb the axis of gyration and thus set up new orogenic forces. Such an interplay of action and reaction may explain the succession of orogenic episodes through geologic time.

THE origin of the forces which have compressed beds of sedimentary rock into mountain folds—at times overturning them, even thrusting one limb of a fold tens of miles past the other—has always been an appealing subject, and there is a great literature on the subject. Secular cooling; chemical and crystallographic changes of minerals comprising the sediments; crowding of the crust through igneous activity; isostatic adjustment, and Reade's isogeotherm theory have all been put forward, but none of them has ever seemed to the writer to be capable of developing horizontal forces of the character necessary to produce the stupendous folding found in the great mountain ranges of the earth.

E. C. Andrews (page 907, Report of the Fifth Pacific Science Congress, and page 251, Vol. LXVII, Proceedings of the Royal Society of New South Wales, 1934) touched on the rotation of the earth as possibly tending to transform vertical isostatic movements into horizontal forces; not only does that appear to the writer to be sound, but it is the writer's opinion that the broader kinetic principles of any rotating object may be applied successfully to the earth in a far wider manner and made to explain intelligently the origin of almost all great mountain making movements. The application of these kinetic principles to this problem will depend on whether it can be proved that the axis of gyration of the earth under the influence of transfers of mass about its surface, may actually shift about within the earth sufficiently to produce substantial forces elsewhere within the earth, as the rotating earth seeks to re-adjust itself to such new positions of its axis.

Before attempting to calculate any quantitative answers, it must be thoroughly understood that a shift of the axis of gyration of the earth does not imply any bodily rotating of the earth on any secondary axis by outside forces—shifting of the axis of gyration of the earth is no more than the natural drift of that axis of gyration, within the earth, without the intervention of any external agency other than solar heat, as the moments of inertia of one section or another of the earth are slightly altered, through erosion, sedimentation, uplift or sinking; accumulation of glacier ice, etc. It may help the reader to understand the problem by citing a homely example: Drop a round flat wooden disc in a wide tub of water, and give it a spin; if balanced, it will spin around on its center; then lightly place a moderate weight at some point near its rim; its "axis of gyration" will instantly shift to a point nearer that weight, the disc will then rotate like an eccentric. Consider the weight dropped on one edge of the disc as sediment removed from the other side of the earth, and the analogy is good, as to either the Northern or Southern Hemisphere alone. But to give a truer (yet not a perfect) analogy to the earth, a pair of such wooden discs, mounted together on a single short spindle, would be required, such that the "off-balancing" of one disc (one hemisphere) could be made to one side, and of the other disc (or hemisphere) to the opposite side—this, to accomplish a tilting of the axis of gyration, instead of simply translating it.

Applying this example to the earth, it is quite reasonable to assume that, as the moments of inertia of one sector or another vary, as a result of transportation of sediments about its surface, there will be some shifting of the axis of gyration within the earth; if such shifting is a tilting of the axis of gyration, a new equator, inclined at an angle to the old equator, will result, and there will be developed north and south forces tending to move the earth's equatorial bulge from the location of the former equator to its new location; also, whether the shifting of the axis is a tilting or a translation, certain parts of the earth will be at a greater radius from the new axis than they were from the old—and for that reason will be impelled to move at a greater lineal velocity than formerly. The forces developed in these latter instances will of course be east-west forces.

Now it will be apparent that any disbalanced sector of the earth, under the influence of the above-described forces, might theoretically move all the way to the locus of zero intensity,* seeking equilibrium, if there were no resistance of friction or otherwise, from the rest of the crust of the earth against such motion.

In other words, there is no near limit to the horizontal distance through which the previously described forces may continue to push onwards portions of the crust of the earth—no near limit, that is, until such forces are balanced by other agencies, such as friction.

This kinetic theory, by reason of the nature of the origin of its forces, totally different from those others mentioned above, is thus uniquely capable of accounting for the great "nappes," representing 50 miles or more of horizontal displacement in the Alps, and in other externally weak parts of the crust.

It will be apparent that the maximum intensity of these forces, either north-south or east-west, will be at some point along the meridians which represent the intersection with the surface of the earth, of the plane which contains both the former and the new axis of gyration. Intensity at other meridians will decrease in proportion to the cosine of the departure in longitude of that meridian from the meridian of greatest intensity.

It can also be shown, mathematically, that as to tilting of the axis, these forces will be greatest at latitude 45 along the said meridians, decreasing to zero at the equator and at both poles; as to a translation of the axis, it can likewise be shown, mathematically, that the forces will be greatest along those meridians *at the equator,* decreasing to zero at both poles.

It can further be shown, mathematically, that the total north-south (or east-west) forces, at any given latitude λ resulting from any given tilt, θ, of the axis, can be represented by

$$4\pi^2N^2rM\cos^2\lambda - 4\pi^2N^2rM\cos^2(\lambda-\theta) \quad \ldots\ldots \quad (1)$$

where N is the rotational velocity of the earth
M is the mass of the earth
r is a mean radius, approximately its radius of gyration.

* The distance might theoretically be as much as 90° of longitude in the case of a tilted axis, or for translation, as to east-west forces; the equator or the nearest pole would be the ultimate limits for the north-south forces

Where there is no tilting of the axis of gyration, but only translation, the total forces at any given latitude can be represented by

$$4\pi^2N^2r\,M\frac{d^2+2dR}{R^2}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Here, N, r, M have the same meanings; d represents the lineal distance of translation of the axis, and R the radius of the earth.

If the forces expressed by the above equation (1) be considered as north-south forces, they can be regarded simply as a local change in centrifugal force to the earth, due to this tilting of the axis.

It is thus possible to measure, quantitatively, the forces expressed by the above equations, by weighing them (considered as a local change in the centrifugal force) against the total centrifugal force of the earth, which is $4\pi^2N^2rM$. We know that it is this total centrifugal force which produces the equatorial bulge; the work done in raising that bulge can be calculated, in terms of cubic miles of crust uplifted so many miles, by a relatively simple plotting of the diameters of the earth at successive latitudes, together with consideration of the circumferences of the earth at those same latitudes. The total work thus done in raising the equatorial bulge by the earth's total centrifugal force, $4\pi^2N^2rM$ works out as equivalent to raising 225,000,000 cubic miles of the earth's crust, 4 miles, vertically against gravity

Applying this to the above equation (1), we find that, for a tilting of the axis of gyration by 10′, 2,500,000 cubic miles of the earth's crust could be lifted 4 miles by these forces, be they north-south or east-west. It can likewise be calculated that a lineal translation of the axis by some 3 miles would produce a substantially equivalent amount of work (equation 2).

Inasmuch as a very considerable part of the work done by such forces is bound to be dissipated as heat through friction (witness the metamorphism observed in almost all folded sedimentary rocks)—we may hazard the estimate that if unrelieved by acceleration of the disbalanced sector, two-thirds of the energy (developed in the earth by any shift of its axis) goes into heat—one-third only into actual elevating of sedimentary rocks, through folding and thrust faulting, against gravity—its only other possible relief. Thus 800,000 cubic miles of

crust, elevated 4 miles against gravity, is a measure of what one might expect, from 10′ shift of the axis. This is of the order of magnitude of the uplifts involved in the Alps-Caucasus-Himalaya or in the American Cordillera.

We will next proceeed to examine whether transportations of sediments of the order of magnitude comparable to geological records might have produced a tilt of about 10′ in the axis of gyration.

Any mathematical calculation of the possible tilt of the axis from such a redisposition of sediments requires an assumption of the volume of those sediments and the distance they were transported. For purposes of this calculation, the writer has selected the widespread deposits of Cretaceous time and has assumed that these deposits at their pristine maximum were, if anything, greater in volume than the present volume of North America, measured down to the ocean floor. As to distance transported, their fine grained sediments may well have been carried 2,000 miles—and in so far as concerns the calcium and magnesium which so much Cretaceous rock carries, if such elements were deposited by precipitation out of world-wide seas, the "travel" of such deposits would be much greater, as every ton so precipitated would draw from the tonnage in solution throughout the world.

With these very general assumptions, the writer has calculated that such Cretaceous deposits may well have caused a tilt of well over 10 minute in the axis of the earth.

This calculation seems to be supported by a calculation of W. D. Lambert of the U. S. Coast and Geodetic Survey, referred to in Bowie's paper in "American Petroleum Institute Symposium" (on Wegener). In that paper, it is stated that Lambert calculated that the hypothetical drift of North America to its present position, from Europe, would have tilted the axis 30 minutes. With volumes and distances substantially identical, the 10 minute plus tilt calculated for Cretaceous sediments seems fairly conservative. Beyond that, as a drifting of a continent would involve only the interchange of rock, density 2.7, with sea water, density 1, while transfer of sediments would involve largely the interchange of rock, density 2.7, with the atmosphere, density 0, (and only to a smaller extent with water, density 1) additional weight would attach to a transfer of sediments, in a comparison with continental drift.

Cretaceous sedimentation, therefore, appears competent to have tilted the axis of the earth by 10 minutes of arc with considerable margin to spare.

Thus we have answers, quantitative to a reasonable degree, to both parts of the problem:

1—Shifts of the earth's axis, as much as 10′, can have taken place as a result of transfers of sediments (continental glaciation and deep seated convection currents, other possibilities, could also contribute); and

2—Shifts of 10′ in the axis have been shown to be sufficient to raise up mountain ranges, comparable to those existing today, even after allowing ample waste of work in friction and heat.

By reason of the lack of homogeneity of the earth's crust, certain parts are naturally more yielding than others. As will be explained below, mountains can develop only in the more yielding sections; but this very ability to yield makes them act as a lens which concentrates into that section forces from a wider section of the earth.

The question will be asked, why did not isostasy, for which there is strong evidence, absorb these disbalances of sectors of the earth at the very start? In a great many instances, it no doubt did absorb them. Only where the crust was unable to yield quickly enough, under isostatic pressure, did these disbalances come into being sufficiently to disturb the earth's axis of gyration. And when the axis was shifted, it still does not follow necessarily that mountain ranges will be lifted up. It does follow, to be true, that horizontal forces will be set up in the crust of the earth. These horizontal forces, if nothing yields, will simply accelerate or decelerate that particular sector of the earth, temporarily out of balance in its kinetic energy (as a result of a change in its radius of gyration) until, by its altered lineal velocity, its actual kinetic energy will fall in agreement with that which the rest of the earth is trying to impress upon it. However, if in the line of those horizontal forces there exists a thick prism of sedimentary rock, more capable of yielding than the rest of the crystalline crust of the earth, it is possible that those yielding sedimentary beds may be folded into mountain ranges by these forces. There is no other way out for these forces—either acceleration of the unbalanced sector, or work against gravity, partly dissipated as heat

of friction. Mountain folds are thus a rather rare phenomenon, depending on a combination of several completely unrelated factors.

It will be recognized that such resulting uplifts, to the extent that they do not sink back by isostasy, constitute a secondary disbalance as to the axis of gyration of the earth, opposite, in general, in effect to that of the disbalance which first initiated those horizontal forces. Thus, to a degree, a disbalance, once started, oscillates back and forth about the surface of the earth, each oscillation decreasing in amplitude, until all its work is dissipated as heat.

It will also be recognized that to the extent that the kinetic energy of the earth as a whole is converted into heat by the above described reactions, to that extent does this kinetic principle operate as a brake on the rotations of the earth. It can be calculated that a tilting of 10′ of the axis of the earth would reduce the rotational velocity of the earth by about 3/1000 of 1 per cent. To the extent that the kinetic forces do work against gravity, to that extent is there no change in the total energy of the earth.

The amount of shift of the axis is thus seen as merely the size of the fulcrum by which kinetic energy, released locally in one part of the earth, is transferred to some other part of the earth: if yielding beds of sedimentary rock happen to be in the path of this transfer, the chances are that they will be folded into mountain ranges, thus converting the energy into work against gravity, or dissipating it as heat.

Professor R. T. Chamberlin has called the writer's particular attention to the fact that there are no indications of deformation by folding on the moon, where applications of equations 1 and 2 above would give vastly smaller results.

Possibly it may some day be found that the very hot white dwarf stars have a high rotational velocity—the cool red-dwarfs a low rotational velocity—pointing to a conclusion at the other end of the scale, that it is a constant state of extreme diastrophism, due to the great mass and high rotational velocity of these white dwarfs, which gives them their great heat.

To apply the above theories to the earth today, we do find the Alps-Caucasus-Himalaya, an east-west range, obviously formed by north-south forces, centering more or less near 45°

north latitude, (the latitude of maximum effectiveness for north-south forces that would result from tilting of the axis).

And the American Cordillera, a north-south range obviously formed by east-west forces, runs right across the equator—strongly suggesting that it is the result of some translation of the axis of gyration (a translation produces principally east-west forces, nor do its forces drop to zero at the equator, as do the forces resulting from a tilting of the axis). An interesting sidelight on such a translation may be found in the reported westward drift of Greenland. Had the axis of the earth been actually translated towards about 80° west longitude, and were the spherical conformation of the earth still adjusting itself slowly, in the polar regions, to that translation, celestial observations over a period of time, for longitude in the Arctic to the east of 80° west longitude, would show an apparent westward drift of the observer as the curvature of polar surfaces was gradually losing its eccentricity.

In conclusion, the kinetic theory of mountain making forces does not demand that all mountains be credited to it; it does not to any degree deny the existence of isostasy; it does, nevertheless, appear as the reasonable mechanical reaction of the rotating earth (acting as a nearly but not an entirely rigid body) to moderate redistribution of mass about its surface due to normal deformations of its surface features by erosion and other causes. Quantitatively, it has been shown that the transportation of masses during whole geological periods are sufficient to have tilted the axis of the earth in the order of magnitude of 10′ (or equivalent translations); and it has been shown that such shiftings of the axis of gyration of the earth would be sufficient to have lifted up the existing major mountain ranges of the earth, after allowing for substantial losses by heat. (Detailed calculations, giving the figures used above, are available on application to the writer by anyone interested in verifying them.)

This kinetic theory of mountain making I thus offer as the principal, although not the sole origin of orogenic forces of the earth.

The writer wishes to acknowledge to Professors Chester R. Longwell and R. T. Chamberlin their many helpful suggestions in developing this subject.

NEW YORK, N Y.

LATE GEOLOGIC HISTORY OF THE PACIFIC BASIN.*

HAROLD T. STEARNS.

ABSTRACT. The Pacific Basin as used herein is that part of the Pacific which lies east of the Sial line and west of the continental shelves of the Americas. Intense folding and faulting in the Pacific region in the Neogene caused enormous quantities of basaltic magma to rise into the suboceanic crust as individual bodies along fissures. These bodies erupted to build thousands of volcanoes, many of which formed long narrow islands and far-flung archipelagoes. Wind and water dispersed animal and plant life chiefly eastward and northward across these island stepping stones Volcanic activity waned at the close of the Pliocene and the higher islands were deeply eroded by streams and cliffed by the sea. During the waning phase the magma reservoirs differentiated, and andesites, soda trachytes, and nepheline basalts were erupted. Each volcano passed through an orderly sequence of phases but some died before completing them all. A great subsidence occurred at the end of the Pliocene deeply drowning valley mouths and causing their rapid alluviation. Coral reefs formed on shore platforms and subsided During the early Pleistocene, part, if not all, of the islands emerged rapidly about 1,000 feet. After this emergence, changes in the volume of the ocean concurrent with glaciations and deglaciations left eustatic strand lines on the islands both above and below present sea level. The later Quaternary was a time of renewed volcanism on a much smaller scale and the building of coral reefs according to the Daly glacial-control hypothesis. Some islands had only scattered lava flows, others had numerous flows sufficient to mask most, if not all, of the eroded Pliocene topography. The later lavas are very diverse petrologic types and apparently include all the nepheline and melilite-nepheline basalts. Stability characterized the islands during the late Quaternary, as shown by widespread eustatic shore lines 5 and 25 feet above present sea level.

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INTRODUCTION.

THE "Pacific Basin" as used herein is the region bounded on the west by the Sial line and on the east by the edge of the continental shelf of the Americas (Fig. 1). The average depth of the Pacific Ocean is about 14,190 feet (Daly, 1939, p. 42). Its area is greater than all the land on earth.

The Sial line lies a little east of the andesite line (Gutenberg, 1939, p. 303). All islands in which continental rocks including silicious plutonics, hornblende andesites, or metamorphics are exposed lie west of the line. The line is the probable boundary of the continental platform of Australasia. Pellets of Tertiary limestones containing *Lepidocyclina* have been found in consolidated beach conglomerate on Jabor Islet in Jaluit Atoll in the Marshall Group (Yabe and Aoki, 1922, pl. 4). These have probably been derived by wave action from outcrops not far below sea level. The Marshall, Gilbert, and Ellice islands appear to lie on great folds at the outer margin of the Australasian platform and they may be underlain by Sialic rocks.

The islands east of the line are called oceanic islands but to zoogeographers this word has a different meaning. Simatic islands would perhaps be a better name, as all are basalt or closely allied rocks or thought to be underlain by them. The islands west of the line are known as continental islands but many carry only oceanic fauna. These islands might be called Sialic islands from the character of their basement, as all are composed of or are believed to be underlain by continental rocks.

The purpose of this paper is to give a brief synopsis of volcanism in the Pacific Basin, based on the writer's work there since 1924.

TYPES OF ROCKS.

All islands within the Pacific Basin are made of lava or coral limestone and it is generally agreed among geologists that all the coral islands have volcanic basements.

The volcanic rocks are predominantly basalt, with primitive olivine basalt constituting more than 90 per cent of the bulk.

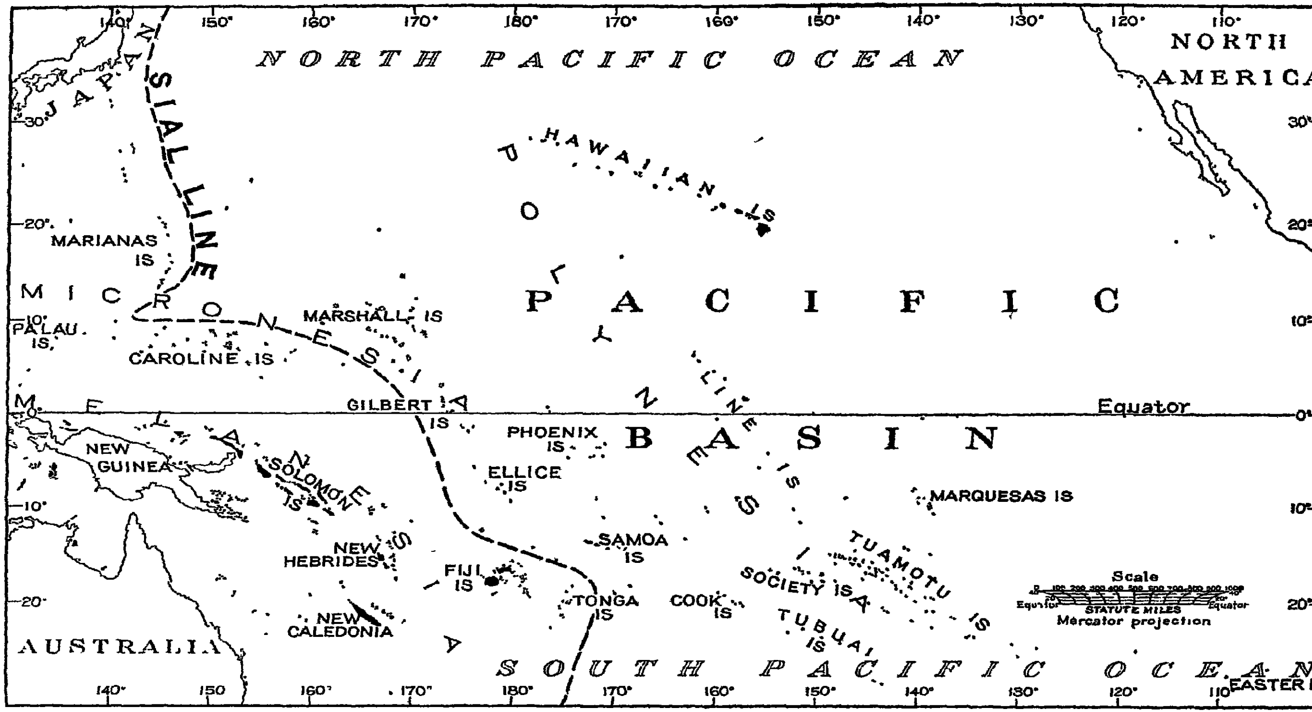

Fig. 1. Map of the Pacific Basin. Sial line indicates probable eastern edge of continental rocks.

Nepheline basalts, melilite-nepheline basalts, picrite-basalts, basaltic andesites, andesitic basalts, oligoclase andesites, and soda trachytes make up the balance. They are chiefly differentiation products of isolated magma reservoirs underlying individual volcanoes (Fig. 2). Dunites, gabbros, and related

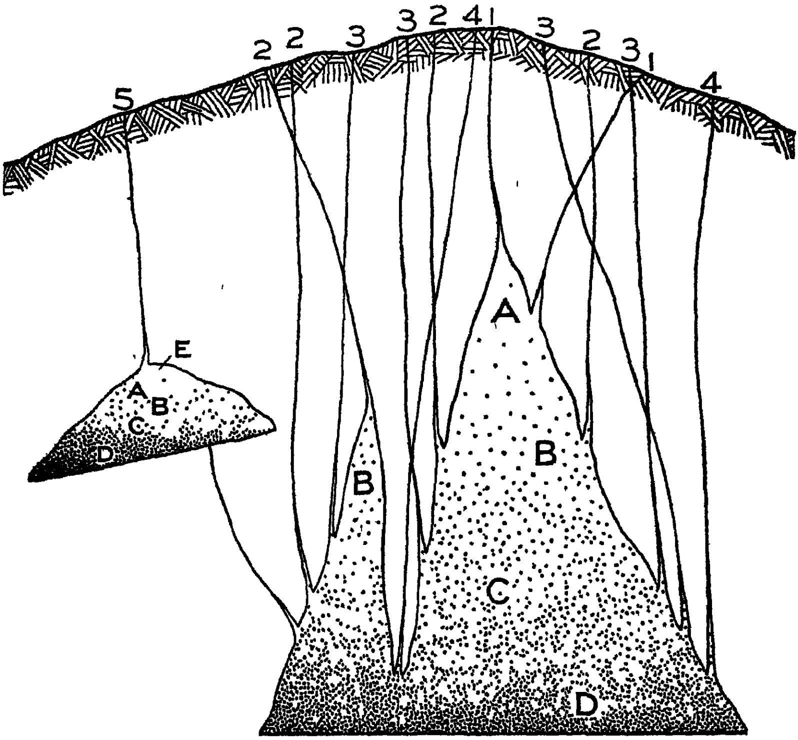

FIG. 2. Diagram illustrating a manner in which lavas of differing composition might be erupted simultaneously from fissures tapping different parts of the magma reservoir. A, andesite; B, basaltic andesite; C, basalt; D, picrite-basalt; E, trachyte; 1, dike erupting andesite; 2, dike erupting basaltic andesite; 3, dike erupting basalt; 4, dike erupting picrite-basalt; 5, dike erupting trachyte (after Stearns and Macdonald, Fig. 45).

coarse-grained silica-poor rocks are found in the eroded cores of some of the volcanoes or as xenoliths in lava flows. Some of these rocks have been mistakenly reported as evidence of subjacent continental rocks. Marshall (1924, p. 733) has clearly shown that no continental rocks have been found in place in Polynesia. The only rock with possible continental affinities is the silica-rich obsidian from Easter Island on the submarine Albatross Plateau. Daly (1938, p. 35) believes

that this obsidian may be remelted granite, but Bandy (1937, p. 1,607), who mapped the island and studied the rocks, believes that it is a differentiate from basalt.

AGE OF THE ROCKS.

The great bulk of the volcanic rocks exposed above sea level is of Neogene or earliest Pleistocene(?) age and these rocks in the higher islands are deeply eroded. Superimposed and usually unconformable on the older volcanics are the much less abundant middle and late Pleistocene volcanics. Least voluminous of all are the Recent volcanics. The oldest known limestone is the emerged Miocene reef on Mangaia Island (Marshall, 1927, p. 44). Most other emerged reef rock is probably Pleistocene.

PLANT AND ANIMAL DISPERSAL.

The form of the Pacific Basin at the beginning of the Tertiary is not well known. We know, however, that the high volcanoes forming the Circle of Fire of the Pacific did not exist. The probable boundary of the former Melanesian continent in the southwest Pacific has been shown on a map by Ladd (1934, Fig. 6). It does not touch Little or South America. Gregory (1930, pp. 72-136) has summarized the biologic and geologic evidence of land bridges, some of which points to the existence of connections between Australia, New Zealand, Antarctica, and South America in the early Tertiary. Simpson (1939, p. 767) concludes, however, "There is no known biotic fact that demands an Antarctic land migration route for its explanation . . ." Some of the conflict in thought regarding these land connections has resulted from considering them to be continental rocks. Perhaps these early bridges if they existed, were extensive basaltic plateaus. Fragments of sunken plateaus would now be indistinguishable from other basaltic xenoliths and ejecta. Zimmerman (1942, p. 306) has presented convincing evidence that there is nothing in the insect faunas "to indicate any great age for their development and nothing that would demand extensive land areas or land bridges in the Pacific."

The writer visualizes the Pacific Basin at the close of the Pliocene as characterized by isolated volcanic cones and many narrow elongate islands built by volcanoes along fissures, some of which were separated from adjacent islands by fairly

narrow straits. The plants and animals (not man, who came much later) crossed on the island stepping stones and spread unimpeded over extensive dome-shaped mountains. They were dispersed chiefly by wind and water from the southwest where islands were close together.

NATURE OF CRUSTAL MOVEMENT.

The mountains stretching southward from Japan through Java to India along the western side of the Sial line have been shown by many geologists to have been built by intense folding which started in the early Tertiary and was vigorously renewed in the Pliocene. Islands at the very edge of the Pacific Basin, such as Guam, show intense folding and overthrust faulting in Neogene time (Stearns, 1940b, p. 1948). The Coast Range of California shows strong folding on the east side of the basin in Miocene and Pliocene time. We can be fairly certain, therefore, that folding characterized the shores of the basin during the Neogene and that orogenic movements continued into the Pleistocene along part of the shores. The basin cracked open along definite lines (Dana, 1894, p. 37) which may have been echelon tension faulting. Hobbs (1944, p. 261) believes they are compressional faults bounding lagging blocks in a sinking crust. Strike-slip faulting has recently been proposed by Betz and Hess (1942, p. 116). Some geologists favor the theory that fault cracks indicate the crests of folds and are evidence of folding (Chubb, 1934, p. 295). Williams (1933, p. 7) thinks that the fault cracks may lie along thrust planes. Whether compression or tension dominated the structure of the basin has not been determined.

MAJOR EPOCH OF VOLCANISM.

The Tertiary movements ruptured the basaltic crust in so many places that enormous quantities of primitive olivine basaltic magma gushed forth. Thousands of islands and submarine volcanic cones in the Pacific were built by this great effusion of lava. Explosions characterized the shallow submarine eruptions. The lack of soils interstratified with these early lavas is proof of the rapidity of their extrusion. It is probable that this epoch of volcanism exceeded in volume and rapidity of extrusion any other since Cambrian time. By the close of

the Pliocene, island after island broke the surface of the Pacific. It is possible that some of the magma was squeezed from under the continents adding materially to the volume of the basaltic substratum under the Pacific Basin. Regardless of its source, the magma must have caused some tumescence.

Detailed studies by the writer of specific volcanic archipelagoes in the Pacific indicate that most volcanoes apparently were not connected directly to a liquid substratum during their late histories. Many thousands of individual gas-charged bodies of magma escaped from the substratum and stoped and melted their way upward. A gigantic earth carnival released its stock of toy balloons and all rose upward against a ceiling of dense rock, kept cool and solid by the superjacent ocean. Each body passed through an independent history, controlled probably in its eruptive mechanism by geophysical and astrophysical forces. Perhaps these forces acted and reacted upon many bodies simultaneously but the time of extinction of each body and the kinds of lava extruded from it were governed by its individual volume, gas content, and form.

Each subaerial volcano passes through an orderly sequence of phases but some die before completing them all. These phases are: (1) Youthful phase when a shield-shaped dome is built of flows of primitive olivine basalt poured out in rapid succession; (2) mature phase with collapse of the summit and rifts of the dome; (3) old-age phase with extrusion of less basic lavas, some of which are as silica-rich as soda trachyte, and filling of the summit caldera; (4) rejuvenated phase following an erosional period with scattered eruptions of diverse types of lava (Stearns, 1940a, p. 1947).

THE GREAT SUBSIDENCE.

The whole Pacific Basin floor apparently collapsed as a result of the extrusion of so much of its underpinning and probably because of plastic basining from the great load of heavy basalts so rapidly piled upon it. But the nearly universal presence of Plio-Pleistocene valleys on the larger islands indicates a relative still-stand before subsidence. On some islands these valleys are deeply buried by eruptives (Stearns, 1930, p. 53). The intensity of the erosion and the great size of the valleys manifest a much greater elevation of the islands than at present. Subsidence reduced the rainfall on many

islands by lowering their summits below the zone of heavy rainfall. The valleys are now choked with Pleistocene débris and all are being alluviated. It was this intense erosional period that gave rise to highly diverse and local ecological conditions which led to "explosive speciation" (Zimmerman, 1942, p. 293).

Collapse and basining of the ocean floor may have started soon after the tumescence was relieved by the first great floods of lava but the deep canyons and high sea cliffs on Neogene volcanoes throughout the Pacific are conclusive evidence that the final collapse of the floor was a delayed action not concurrent with the peak of volcanic activity. Stream and marine erosion is rapid on tropical islands of jointed thin-bedded lavas; hence, the delay, measured in years, may not have been long.

We know from deeply drowned platforms and valleys that the subsidence was great. Dana (1890, p. 366) believed the subsidence over a vast area of the Pacific amounted to 10,000 feet. Unfortunately most of the evidence is drowned. We can, however, obtain a crude estimate of plastic basining. If the Fennoscandia icecap 6,000 feet thick could isostatically depress the center of land under it 900 feet (Daly, 1926, p. 190) it is reasonable to assume the weight of basaltic masses 3 to 7 miles high, typical of Pacific islands, could depress the adjacent floor of the Pacific Basin a matter of a mile or more.

Betz and Hess (1942, p. 109) have computed from gravity anomalies that the downbowing under the Hawaiian Islands amounts to 35,000 feet. Some errors are involved because of the scarcity of data, but their computation suggests the order of magnitude. If such a basining occurred under each volcano, the sum total of downbowing alone would be appreciable for the entire Pacific Basin. Many geologists, unfamiliar with the Pacific, find it difficult to imagine so great a change in the Pacific floor in late geologic time, but those who have done detailed work here are impressed with the magnitude of the change. Stanley (1924, p. 766), government geologist of Papua, writes, "There have been some stupendous earth movements during late Tertiary times—commencing probably in late Miocene and reaching a maximum in Late Pliocene or early Pleistocene." Marshall (1924, p. 734) states, ". . . a downward movement of parts of the ocean floor of great amount has taken place in recent geologic time."

Fracturing and folding along the Pacific borders concomitant with the sinking led to the eruptions, chiefly andesitic, that added to the bulk of the circum-Pacific volcanoes. The deeps of the Pacific that border the basin probably were deepened greatly at the close of the Pliocene by downfaulting of the Pacific Basin and uplift of the ocean floor to the west.

The great subsidence of the floor of the Pacific Basin resulted in the drowning of canyon mouths of the older eroded islands in the Pacific. The gradual submergence of thousands of islands and banks in the coral seas gave rise to ideal conditions for reef development, especially atolls. The shore platforms and shoals so necessary for coral colonization had been prepared by planation and sedimentation during the preceding still-stand and vigorous erosion period. Coral atolls grew as living monuments to departed islands.

RENEWED VOLCANISM.

The later Quaternary was a time of renewed eruptions in the Pacific islands but much less lava was produced than in the Pliocene. Some islands, such as Oahu and Tutuila, had only scattered lava flows but on others, such as Hawaii and Savaii, fairly large volumes of lava were extruded. These eruptions were commonly characterized by diverse types of lava depending on the length of the repose period and the extent of local differentiation in the magma chamber under each volcano. The late lavas range from ultrabasic nepheline basalts through basalts and andesites to the silicious obsidian of Easter Island.

PLEISTOCENE EMERGENCES AND SUBMERGENCES.

Shore lines more than 560 feet above sea level (Stearns, 1938b, pp. 618-621; 1945) indicate that the floor of parts, if not all, of the Pacific Basin rose rapidly after the great subsidence. The emergence in Plio-Pleistocene time probably preceded all strands made by fluctuations of sea level caused by glaciation and deglaciation. How much the continents rose eustatically remains to be determined. They may have risen also from Sima being squeezed under them from the adjacent ocean floor.

The general absence of pillow lavas in the islands of the Pacific Basin is indisputable proof that the islands were formed

subaerially prior to the great submergence and subsequent emergence. The only authentic pillow lavas so far reported lie close to sea level on Kauai in late valley-filling lavas that partly filled Waimea Canyon where plenty of water was available for their formation (Stearns, 1938a, p. 26). Stark (1938, p. 235) reports pillow lavas on Borabora Island, but points out that they have a subaerial origin and do not indicate former submergence. His illustrations indicate that they are not detached pillows but are sections of elongate toes and other bulbous masses characteristic of subaerial thin pahoehoe lava flows.

The basement rocks of islands west of the Sial line are characterized by pillow lavas and marine fossiliferous tuffs of Tertiary age indicating that they are submarine volcanoes elevated above sea level. Plio-Pleistocene coral reef limestones, little disturbed, lie unconformably on these older rocks up to 1,200 feet above sea level (Mawson, 1905; Stearns, 1940b, p. 1948). The western islands with their long undersea history stand in strong contrast to the subaerial volcanic islands in the Pacific Basin.

All the older islands in the Pacific Basin, not veneered with late Pleistocene lavas, show evidence of shifting sea levels concurrent with Pleistocene glaciation and deglaciation. The 5-foot and 25-foot eustatic shore lines, last in the series, are well established in the Pacific (Stearns, 1941). Earlier strands above and below sea level are being deciphered slowly (Stearns, 1935, and 1945). Stability characterized the islands during the late Quaternary.

ORIGIN OF REEFS AND ATOLLS.

The Pleistocene was an epoch of rapid reef building. Reefs formed early in this epoch are deeply drowned in the Pacific Basin but many lie considerably above sea level on islands west of the Sial line. Many of the reefs were built on antecedent platforms according to the Daly hypothesis of glacial control but the effects of the fluctuations of sea level are deciphered with difficulty until near the close of the Pleistocene. The lowered sea level accompanying the Wisconsin glaciation bevelled off some of the previously formed reefs. Those left above the lowered sea weathered under tropical atmospheric agencies, always extremely effective in destroying limestone. When the

sea rose in Recent time due to the return of the glacial melt water, coral colonies reinhabited shelves of whatever origin and grew upward on the backs of the older reefs and atolls. The rise was so rapid that reefs did not develop on steep shores (Stearns, 1944, p. 1325). Thus the Marquesas Islands and many parts of the coasts of islands in the Hawaiian and Samoan groups are reefless now.

SUMMARY.

1. Intense folding and faulting in the Pacific region in the Neogene caused enormous quantities of basaltic magma to rise into the thin suboceanic crust and form individual reservoirs along fissures.

2. Tremendous quantities of basalt were erupted in the Neogene. Chains of volcanoes, which formed fairly close-spaced islands throughout much of the Pacific, were built.

3. Animal and plant life spread on island stepping stones, chiefly northward and eastward from Australasia because the islands were closer together in the southwestern part of the Pacific. Stream erosion deeply furrowed the higher islands and waves battered the shores into high cliffs. Highly diverse topographic and climatic conditions induced explosive speciation.

4. Compensation for the huge volcanic piles caused the Pacific Basin floor to sink a large amount. Apparently an eustatic and epeirogenic rise of the continents resulted but the extent of rise has not been determined. Parts of the shores bordering the basin were tilted and uplifted.

5. Coral reefs and atolls developed to great thicknesses on platforms and banks as they subsided. These reefs are now deeply drowned.

6. A rapid emergence, possibly eustatic, of about 1,000 feet of at least part of the floor of the basin occurred in early Pleistocene time.

7. A series of eustatic fluctuations in sea level accompanied glaciation and deglaciation. These fluctuations left narrow emerged reefs and weak shore lines on most volcanic islands. Pleistocene volcanics, commonly building up banks and extending platforms, became favorable sites for reefs. Some of the reefs formed during the periods of subsidence, in the early and

middle Quaternary were bevelled by the lowered glacial seas in late Quaternary and many, where the coast was not too deep, developed on their backs new thin reefs according to the Daly glacial-control hypothesis.

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DISCUSSION.

IOWAN AND TAZEWELL DRIFTS AND THE NORTH AMERICAN ICE SHEET.

RICHARD FOSTER FLINT AND HERBERT G. DORSEY, JR.

Two Conflicting Concepts.

THE senior author recently advanced the hypothesis that during the Wisconsin Glacial Age North America east of the Rocky Mountains was glaciated not by two originally separate "Keewatin" and "Labrador" ice sheets but by a single Laurentide Ice Sheet, developed by westward growth from initial glaciers occupying highlands in the northeastern part of the continent (Flint 1943).

In a paper aimed at broad regional correlation of the Wisconsin drifts Antevs (1945) suggests that the concept of a single Laurentide glacier is incompatible with the age relations of the Wisconsin drifts west and south of the Great Lakes. He thinks it improbable that Laurentide ice could have grown far enough west to build the Iowan drift in Iowa without having built, at the same time or even sooner, a drift having the areal distribution of the Tazewell drift in Ohio, Indiana, and Illinois. Since, as is well known, the Iowan drift is at least several thousand years older than the Tazewell. Antevs rejects the single-ice-sheet concept and states his continued adherence (with some modifications) to the scheme proposed in 1916 by Enquist (1916), and summarized later in the present paper.

The principal question, then, is this: does the fact that the Iowan drift is older than the Tazewell drift dispose of the concept of a single Laurentide Ice Sheet which grew westward from origins in the northeast, and demand instead a return to the idea of a separate "Keewatin Ice Sheet" which spread southward and reached northern Iowa before a separate eastern glacier could reach northern Illinois? Or, on the other hand, is the age difference compatible with the concept of a single Laurentide ice mass?

The present writers are aware of the problem implicit in the offset dates of the Iowan and Tazewell drifts. It was pointed out by the senior author (Flint, p. 337) that the areas of greatest precipitation and net accumulation of glacier ice constituted domes on the ice surface, and that these domes shifted in response to variation in snowfall. This statement deserves amplification, which is given in the following section.

Existing Climate and the Zonal Index.

Any attempt to interpret the climatic conditions of a former time must be based in large part on our knowledge of the general atmospheric circulation that operates at present. Although the existing glaciers in the northern hemisphere are of small combined extent compared with their extent during the Wisconsin maximum, present-day climates are not radically different from the climates of that former time. A little cooling would offset the net wastage that is now in progress and would bring about once more the widespread growth of glaciers. Hence the use of existing climatic factors as a basis for interpreting glacial climates is believed to be appropriate and essentially reliable

Meteorologists searching for improved methods of long-range forecasting have found an important clue to the problem of relating large-scale weather changes to the general atmospheric circulation. The velocity of the westerly winds in the belt between 35° and 55° North Latitude has been taken as an index (the *zonal index*) of the general atmospheric circulation in the northern hemisphere. A significant correlation exists between the value of the zonal index on the one hand and, on the other, displacements of the subtropical highs, subpolar (Aleutian and Icelandic) lows, polar highs, and storm tracks.

In a typical high-index circulation pattern the subtropical highs and the subpolar lows are well developed and extend inland over the continent toward the east at higher-than-normal latitudes. The polar highs may be well developed in the Arctic region, but outbreaks of cold polar air come southward only over the eastern parts of the continents, where they are blocked by strong, middle-latitude westerlies. In contrast, low-index conditions are characterized by meridional rather than zonal movements. Subtropical highs and subpolar lows are split into several relatively weak cells and are displaced southward from their normal latitudes. Polar highs come down strongly over the western as well as the eastern parts of the continents, and at times of extremely low index they extend even to the western coasts themselves.

Thus the zonal index is a valuable tool in the analysis of long-range weather trends. It should have value, also, for the synthesis of climates in the geologically recent past. Making use of probable major trends in index averages over periods of about 10,000 years, we propose to deduce the probable climatic conditions in North America during the Wisconsin Glacial Age.

Climatic Conditions in the Wisconsin Age.

For the beginning of the Wisconsin (or any other) Glacial Age a secular reduction in temperature is assumed. Because cold dry

regions lose heat more readily than warm moist lands and water bodies, the first result of general cooling would have been an increased thermal gradient between high and low latitudes. This in turn intensified the atmospheric circulation (that is, set up a predominantly high-index circulation pattern) in the middle-latitude zone.* Reduced temperatures and cyclonic storms associated with high index values brought increased snowfall (and reduced summer ablation) to two regions first: the coastal mountains of western Canada and Alaska, and the highlands of northeastern North America—notably of eastern Quebec—where the high-index circulation patterns of today's winters often result in colder than normal temperature conditions. At the same time the strong zonal circulation created extremely warm foehn winds on the eastern flank of the Rocky Mountains.

It is improbable that the snowfall that nourished the first glaciers in the northeast came from Atlantic easterlies as Antevs believes. The easterlies and northeasterlies today do not bring much precipitation to eastern Canada and Labrador. Rather they serve as a wedge of cold air over which warm air masses, approaching from southerly and westerly directions, are forced to rise and release their moisture.

The "Alberta Low," a well-known type of storm originating in Alberta at times when warm foehn winds interact with Canadian polar air, is a conspicuous product of high-index cyclonic activity in the North Pacific region. Its track lies across the Great Plains of Canada, passes between the Great Lakes and Hudson Bay, and over the region of the lower St. Lawrence. The cyclonic storms that follow this path have definite characteristics. They are fast-moving systems with no persistent outbreaks of cold air in their rear. Their northeast quadrants bring heavy snowfall to eastern Canada and Labrador, but the cyclones bring above-normal temperatures to the region south of the track. These facts suggest that long-continued high-index activity would have favored the extension of an ice sheet in eastern Canada toward the west but not toward the south.

It is not probable that during this phase high-index conditions were continuous. No doubt the zonal circulation was weak at times, just as it is at times during the winter seasons of today. But when low-index conditions develop, the "Aleutian" and "Icelandic" cyclonic centers tend to split, and outbreaks of cold air characterize interior North America. Such conditions are ideally depicted in a chart prepared by Rossby (1941, Fig. 15). They favor heavy

* For a discussion of the correlation between general circulation patterns and index values see Willett 1944.

snowfall in the southern Canadian Rockies and in eastern Canada, but would bring little snow to the Keewatin district. Further, these conditions bring with them variable temperatures, which, in the region east of the Mississippi, might be either cold or warm.

By the time a fair-sized ice sheet had developed in eastern Canada, with resulting semipermanent high pressure over it, the extensive glacier ice in Alaska and northwestern Canada would have favored persistent cyclonic activity throughout the year in the Gulf of Alaska and over Pacific waters to the south, as Antevs (1945, p. 12) suggests. At times when the circulation was strong, occasional storms were able to cross the Rockies, moving generally southeastward and bringing snowfall to the western and southern borders of the growing ice sheet in eastern North America. On the other hand, at times of weaker circulation, storms would frequently have stagnated in the Mississippi valley region, between western and eastern high-pressure cells, before moving slowly eastward. In the northwestern quadrants of these storms, Tropical-Gulf moisture would fall as snow, but the eastern sectors would receive wet snow followed by heavy rain, and subsequent light snow flurries as the storms moved eastward. During this type of circulation temperatures would be relatively low in western United States. In the east they would be higher because of the strong, warm southerlies that checked the spreading of the ice sheet in the Great Lakes region but ran on aloft to bring heavy snowfall to Quebec and Labrador.

Continued worldwide cooling and glaciation of increasing continental areas would have been increasingly favorable to a weak type of circulation pattern. Hence the index, having started out with high average values, must have fallen progressively to low values. In western United States the lowest values would have been reached when, as Antevs indicates, the development of glaciers in northwestern North America induced increasingly low temperatures in the southern Canadian Rockies. According to present knowledge this behavior of the index is reasonable and expectable because extremely cold weather in the far west occurs only with very weak circulation patterns. During the gradual change, extension of the growing Laurentide Ice Sheet toward the west, where temperatures were low, rather than toward the south, where they were higher, would have been favored Eastern United States should have been relatively warm Thus the entrance of a lobe of ice into the region west of the Great Lakes before the ice reached its fullest extent south of Lakes Michigan and Erie is consistent with the development here outlined.

Recent studies of the relationship between zonal indices and North American weather anomalies have shown that with a rising index, warming begins in the west and then extends slowly east-

ward—though even with very high index values some outbreaks of polar air may occur in eastern sections.

Because of this present-day relationship it seems probable that a general rise in temperature, such as that which started the shrinkage of the ice lobe responsible for the Iowan drift, would have been accompanied by a shift toward a higher-index type of circulation. Subsequent warming should have been pronounced in western North America. In contrast, eastern sections would have received frequent outbreaks of cold air moving down from over the ice sheet in the rear of "Alberta"-type lows skirting the southeastern edge of the glacier far south of their present track. This contrast between the eastern and western regions appears to provide the conditions requisite for the extension of the Tazewell ice to its maximum, while the Iowan ice was shrinking. Presumably the Tazewell advance was checked when a return to lower index values again brought warmth to the eastern region.

It should be noted that these fluctuations were comparatively short. The best calculations from the degree of decomposition of each of the drift sheets suggest that the Tazewell ice began to shrink about 10,000 years after the Iowan ice had begun to waste away, and that the Cary and Mankato maxima followed each other at intervals of about 10,000 years. In contrast, probably at least 40,000 years and perhaps many more were required for the growth of the ice sheet to its Iowan maximum.

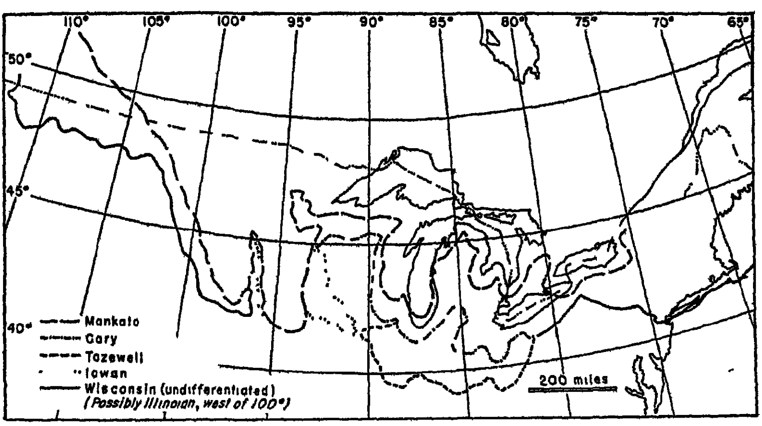

Fig. 1. Wisconsin drifts in central and eastern North America. (*Approximate; compiled from various sources.*)

A map (Fig. 1) showing the distribution of these drifts indicates that the border of the ice south of Lakes Michigan and Erie need not have stood more than 100 to 200 miles north of its extreme

Tazewell position at the time when the border west of Lake Michigan stood at its Iowan maximum. Thus the discrepancy in actual extent east and west of the Mississippi River at any one time is not necessarily of a large order. What the actual discrepancy was is not determinable from the facts now available.

Similar fluctuations in index values resulting from secular temperature fluctuations seem to explain equally well the growth of the later Mankato ice lobe west of the Mississippi River. The trend of the glacial features in northern North America, so far as they are yet known, likewise suggests that the post-Mankato shrinkage took place more rapidly in the region between Hudson Bay and the Rocky Mountains, than in northeastern North America This relationship too is compatible with the gradual rise in index and increased zonal circulation that would have been associated with worldwide rise in temperature.

The writers do not pretend to insist that the analysis just outlined is the true explanation of the age relations of the Iowan and Tazewell drifts. They are well aware that the fluctuations in the areas of greatest snow accumulation on the ice sheet may have been the result of many different factors. They hold only that the scheme is reasonable and that it answers Antevs' statement that a single ice sheet is improbable.

THE HYPOTHESIS FAVORED BY ANTEVS.

The foregoing scheme is deductive—in the present state of our knowledge it can not be otherwise—and so is that of Enquist as modified by Antevs. The latter scheme begins the growth of glaciers in the mountains of western Canada. Between Latitudes 55° and 60° the glacier ice spreads eastward, in the form of piedmont glaciers, on to the plains. Spreading is induced by the drifting of snow by westerly winds and by direct snowfall from cyclones that cross the glacier from the direction of the Pacific. The passage of these cyclones is admitted to require that the area be depressed 2000 to 3000 feet below its present height. This is accomplished by subsidence under the weight of the growing ice sheet. By such eastward spreading "the piedmont glaciers over long ages developed into the Keewatin ice sheet" (Antevs 1945, p. 11).

Objections to Enquist's scheme have been cited by Flint (p. 336). Two additional objections should be stressed. The first is that subsidence of the crust amounting to 3000 feet, under glacial loading, would require a thickness of about 9000 feet of ice Resting on a base which in its present ice-free state stands 2000 feet (major valleys) to more than 7000 feet (higher summits) above sealevel, this ice, even after subsidence, would present to penetra-

tion by cyclones a barrier more formidable than the barrier existing there today. The second objection is based on analogy with present-day air circulation. As already indicated, a strong zonal circulation creates unusually warm foehn winds on the east flank of the Rocky Mountains. Therefore persistent warm foehns are expectable in that region during the early part of a glacial age. The resulting high rate of ablation of eastern Rocky Mountains glaciers would have tended to inhibit eastward spreading of Cordilleran ice. This factor alone might have prevented such spreading entirely.

Conditions in Northeastern North America.

In further support of the scheme he favors, Antevs states that although local glaciers may have developed early in the mountains of Labrador, an initial reduction of temperature could not have led to ice-sheet growth in that region as deduced by Flint (1943, pp. 347-352). "A temperature lowering alone could not produce even large piedmont glaciers in that region" he asserts (Antevs 1945, p. 15). Neglecting the highlands of eastern Quebec, he states that the Labrador highlands are too far north of the principal storm tracks to receive much precipitation. With Enquist he derives the snowfall for this region from northeasterly winds This could not have become important, he thinks, until the Iceland low had been displaced well to the south. This, in turn, could not have been accomplished until ice sheets had become well established in Greenland, northwestern Europe, and northwestern North America. Hence the greater age of the Iowan drift compared with that of the Tazewell drift.

In reply, two chief points require emphasis.

The first point concerns the position of the significant highlands with respect to storm tracks. The present writers regard the highlands of eastern Quebec as a more important first locus of ice accumulation than the mountains of the Labrador coast to the northeast. The "principal storm tracks" referred to by Antevs represent the average of all index conditions, including high, low and intermediate. But, as already indicated, the primary phase of glacial accumulation would have been characterized by predominantly high-index conditions. These would have involved a series of "Alberta lows" whose path across Quebec lies north of the average storm track. Further, eastern Quebec lies in the region over which Arctic air thrusts southward persistently even under high-index conditions. The combination of high altitude and persistent wedges of polar air made the Quebec highlands specially favorable for snowfall from high-index storms passing eastward along the

St. Lawrence lowland to the south. True, these storms moved rapidly, and no one of them could bring the amount of snowfall that would result from a slowly moving low-index storm fed by tropical air. But these speedy high-index lows were very numerous. And we must keep in mind that conditions here very early favored the persistence of fallen snow (Flint 1943, p. 349).

The second point concerns the supposed nourishment of glaciers in Quebec and Labrador by northeasterly winds. Easterlies and northeasterlies are not responsible for a large proportion of the precipitation received by that region today. The eastern slopes receive a relatively small amount of orographic snowfall from Polar-Atlantic air, but most of the snow falls on both eastern and western slopes from overrunning warm moist air having southerly rather than easterly components aloft. Here the easterlies act as a cold wedge rather than as a major source of precipitation.

Geologists have not realized fully the implications for the development of former glaciers, of a relationship now widely recognized by meteorologists. This is that in eastern North America lack of precipitation is a result, not of lack of moisture in the atmosphere, but of lack of the conditions necessary for precipitating it. It is therefore unnecessary to postulate, for this region, that precipitated moisture was brought from the nearest large water body, when observation of present-day conditions shows that it is brought from elsewhere.

Apparently the southward displacement of the Icelandic low invoked by Antevs has little bearing on the development of glaciers in Quebec and Labrador. Such a displacement corresponds essentially to the southwest cell of the present-day "split Icelandic low," which develops with low-index conditions (Willett 1944, p. 148). According to the synthesis put forward in the present paper, high-index conditions, rather than low-, should have dominated during the inception of glaciation. Later, during low-index conditions, the southwest cell of the "split Icelandic low" was an important factor in the production of heavy snowfall over Quebec and Labrador. However, as indicated earlier, such conditions developed before rather than during the Tazewell maximum.

It should be emphasized that the normal pattern of temperature and precipitation across Canada from the Plains to Labrador (Reed 1941, pp. 666-668) implies that a general reduction of temperature would favor the formation of ice in the Quebec region rather than in the Keewatin region.

Antevs makes two statements (Antevs 1945, p. 8) that demand, for the record, special comment:

1. "The ice growth leading to the Iowan maximum took place, as far as known, *only in northwestern North America* [italics ours],

west of the 95th meridian and the upper Mississippi River." The words we have italicized create the impression that the Iowan ice lobe originated far to the north and west. Actually the geologic evidence provided by the Iowan drift proves nothing more than that the ice that deposited it came from north of the area covered by that drift, and that it crossed Precambrian rocks en route. (*Cf.* Flint 1943, p. 336).

2. "At any rate there was no comparable ice accumulation in the northeast." On the contrary the geologic evidence tells us only that Iowan drift has not been recognized east of the Mississippi River. It may be present beneath younger drift anywhere within that region. We simply do not know the position of the ice-sheet margin in eastern North America, at the time of the Iowan maximum.

In addition Antevs (1945, p. 8) groups the Tazewell and Cary drifts into a single "maximum," although the writers know of no geologic evidence that justifies such a grouping, and although this grouping is inconsistent with Antevs' strong emphasis on the time difference between the Iowan and Tazewell maxima. But the geologic evidence does indicate that the Cary maximum was separated from the Tazewell maximum by about the same amount of time as that which separated the Tazewell from the Iowan (Thornbury 1940). These data support the writers' general position that an adequate scheme of ice-sheet growth must be flexible because it has to embrace many variable factors. Enquist's scheme possesses a greater rigidity in respect to the dates of the Wisconsin drift sheets than does the concept of a single ice sheet affected by fluctuating climatic conditions along its southern margin.

Conclusion.

In conclusion, if the region glaciated during the Wisconsin Age is viewed in its entirety we are compelled to acknowledge the fact that we have geologic information on only a small proportion of it. As the geology of the western and nothern areas becomes better known, particularly as regards the sources of the various drifts in those sectors, syntheses can be built on much firmer ground than is yet beneath us. Even in well-studied eastern United States, subdivision of the Wisconsin drift has not yet been accomplished because of the absence of carbonate content which has proved successful as a basis for subdivision in the central region. In view of this general ignorance the writers would hesitate to base any far-reaching scheme on the presence or absence of any given drift in the East. They would not brush aside, with Antevs (1945, pp. 4-5), Bryan's suggestion that Iowan drift may be present on Long Island.

Yet even in our present unsatisfactory state of knowledge deductive schemes aimed at general synthesis have distinct value so long as their true relationship to the facts is not lost sight of.

In the present case Antevs, basing his argument mainly on difference in age of the drift sheets of two glacial lobes, adheres to a scheme created by Enquist largely to explain a "Keewatin center" then believed to be a fixed and long-enduring feature. On the other hand the present writers contend that this age difference is more simply explained by differences in the positions of areas of maximum ice accumulation and radial outflow at different times in a single ice sheet. They suggest a climatic mechanism that is consistent with present meteorological knowledge. Their interpretation is based on the recent work of Rossby and Willett, who have evolved successful methods of long-range weather analysis and forecasting from studies of the zonal circulation. The writers believe than an objective appraisal of the two opposing concepts, in the light of the recent discussion by Antevs and of the present paper, does not justify a change in the statement earlier made by Flint (1943, p. 359) regarding the suggested growth of a single Laurentide ice sheet: "The available facts do not prove that the ice sheet originated and developed in this way, but the data assembled are believed to show that this mode of origin and growth is both topographically and climatologically probable; . . . and that the hypothesis explains more satisfactorily the facts we possess than does any other thus far proposed."

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SCIENTIFIC INTELLIGENCE

CHEMISTRY.

The Characterization of Organic Compounds; by SAMUEL M. McELVAIN. Pp. ix, 282; 16 figs. New York, 1945 (The Macmillan Co., $3.40).—This new laboratory text is designed for the use of senior undergraduate or beginning graduate students in a course in the identification of organic compounds. The scheme of analysis used is much like that introduced by Kamm, based in part on solubilities and in part on "class reactions." The first half of the book is an excellent and fairly comprehensive discussion of laboratory manipulations and the theoretical background necessary for effective work in this field. These chapters assume a good knowledge of organic chemistry on the part of the student. A number of practice questions and exercises accompany each chapter. The generous use of modern concepts of valence and acid strength as aids in predicting solubilities is especially to be commended.

The latter half of the manual is taken up by laboratory directions for performing the "class reactions," solubility tests, and preparation of derivatives. Rather comprehensive tables of common organic compounds include the properties of suitable derivatives in each class. These tables are extensive enough to eliminate largely the use of other reference books by the student.

The author has contributed an excellent, carefully written text for a specific purpose; it will be welcomed in those schools that teach identification of organic compounds as a second-year course.

JAMES ENGLISH, JR.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Mainsprings of Civilization; by ELLSWORTH HUNTINGTON. Pp. xxi, 660; 83 figs., 26 tables. New York (John Wiley and Sons, $4.75).—Huntington considers human history as the resultant of four basic forces or conditions: first, a "great unknown force which impels all kinds of evolution", second, biological inheritance; third, physical environment; and fourth, cultural endowment. In the historical sequence these are simultaneous and inseparable. "All are essential, and all play a part in every phase of activity." Yet their several contributions and limitations can be analyzed for study, and should be analyzed if the human story is to be understood. The first factor is, at present, inexplicable. Its existence is (Huntington believes) demonstrated by what is known of evolution but it can neither be understood nor explained in a scientific sense. Its

discussion belongs to philosophy (or metaphysics) and the author does not now propose to enter this dark and stormy field. The last, cultural, factor provides most of the subject matter of orthodox history and has been considered in sufficient detail, but perhaps in too great isolation, by a multitude of students. Huntington plans an eventual synthesis that will include the cultural as well as the biological and physical factors in historical trends. His present study is concentrated on the relatively (but only relatively) neglected influences of inheritance and environment.

About one-third of this book is devoted to the topic labeled "Heredity," an inadequate label because the subject is the influence of biological evolution on mankind and its history. Emphasis is on natural selection and the point of view is completely neo-Darwinian. In recent years this point of view, which seemed headed for oblivion a generation or so ago, has become not only respectable but also almost inevitable. Nevertheless Huntington's treatment, like that of certain of the anthropologists on whose work he relies heavily, suffers somewhat from inadequate, or at least inexplicit, recognition of the essential neo-Darwinism of the argument and from ignoring the recent biological studies (by Haldane, Huxley, Wright, Dobzhansky, and many others) that have given this position its strength and validity.

Huntington's thesis here, as nearly as the reviewer can summarise two hundred pages in one sentence, is that there are hereditary differences between men not only in morphology but also in mental ability, activity, and character, that some historical events (most clearly those involving migration) have been selective as regards these differences, that group as opposed to individual differences have thus arisen, that these group differences have been perpetuated by heredity and the breeding structure of the population, and that they have had a decided influence on the history of the groups concerned and on their neighbors. Some items of the evidence are weak and all together, as Huntington recognizes, do not constitute decisive proof. In the nature of things, such proof will always be very difficult if not impossible, but this reviewer finds that Huntington and his cited authorities have made out a good case for this theory.

This conclusion is highly controversial and its recent involvement in racist ideologies has made it obnoxious to many humanly admirable but perhaps too humanly emotional students of anthropology and, to less extent, of biology. Properly abhoring the fascist philosophy, these students have felt impelled to deny the theory of group differences in innate ability, a theory that seemed to them to support this philosophy. They have taken the possibility that

such differences might be cultural as proof that they are not hereditary, a conclusion that comes from the heart as much as from the head. As nearly as can be judged in the present very imperfect state of knowledge, a more valid and dispassionate judgment seems to be that some such differences may be mainly cultural and some mainly hereditary but that most are probably the outcome of differences in both culture and heredity and of the interaction of these factors. Huntington's treatment of this subject, bitterly as it may be attacked by the currently powerful culturist school among anthropologists, should be a useful corrective for their too extreme reaction against the racists and should facilitate a return to a more objective middle-of-the-road position.

Huntington draws particular attention to the concept for which he proposes the new term "kith." A kith is defined as "a group of people relatively homogeneous in language and culture, and freely intermarrying with one another." The concept is neither as new nor as controversial as Huntington seems to think. His "kith" is merely the habitually interbreeding population of neo-Darwinian geneticists and systematists, applied to a particular species, *Homo sapiens,* in which the delimitation of such populations includes some social factors absent or less prominent in other species. The specification of language and culture in the definition is a weakness, dragging in two of the many factors that lead to interbreeding and uselessly obscuring the primary characteristic of the unit, which is that it does interbreed. It would be equally correct, but of equally secondary import, to add that a kith is also usually relatively homogeneous in morphology and thus more plainly to relate the concept to the field of racial theory, which Huntington, influenced perhaps in spite of himself by the culturalists, is seeking to avoid. The value of the concept in anthopology, as in biological systematics, is that it substitutes for a more morphological criterion the genetic criterion that is a basic determinant of the morphological and of some other characteristics involved. A "kith" is simply a genetically defined race or micro-race, but the new term may be useful in avoiding the emotional implications that have become entangled with the word "race."

The remaining and longest section of the book, "Physical Environment and Human Activity," also contains much new matter but it may be viewed primarily as a summary of the main body of Huntington's abundant researches throughout the last 45 years or a convenient repackaging of the gist of his many previous books, from "The Pulse of Asia" (1907) to "Principles of Economic Geography" (1940). Huntington's main thesis is well-known: climate affects the quantity and quality of human activity; the distribution

of climates and the secular and cyclic changes in climate have been factors in the distributions and movements involved in cultural history. This thesis has had a profound and stimulating effect on geographical and historical research. It has been so extensively discussed that a critic can have little new to say of it at this date. Many details have required modification and some remain highly debatable in the present reconsideration and summary, but the theory in its broad outlines has stood up well and is now rather widely accepted, even though subject to certain reservations.

One criticism, or misunderstanding, should be laid to rest by this book: that Huntington and his school have tended greatly to overemphasize the role of climate in history or to attempt a primarily climatic interpretation of history. Detailed discussion of one historical factor naturally concentrates on this factor and must often seem myopic to the student whose concentration falls elsewhere. This can justly be called overemphasis only if the importance of other factors is denied or unduly depreciated, and this is a fault of which Huntington is not guilty. This book emphasizes the biological element in history as strongly as the environmental. The cultural element is not included among the topics for treatment, but its always great and often dominant influence is recognized throughout.

In matters of detail, there are still many points on which very broad inferences rest on quite restricted evidence and even some that deserve to be called pure speculation, as the author freely admits. This reviewer feels that the sizable (22 pages) section on religion and physical environment is as much a subjective fitting of scanty data into the framework of a preconceived theory as a seriously scientific and objective treatment of this exceptionally difficult subject. Other readers are likely to have similar qualms regarding other topics. This does not seriously detract from the value of the book as a whole. So encyclopedic a discussion has great total weight and impact but cannot be expected to have equal strength throughout. Even the apparently wildest associations of data have at least the merit of suggesting new approaches to the subject and the possibility of leading to unexpected discoveries, whether or not all the present tentative interpretations stand up in the future.

In addition to the concept of kith, discussed above, Huntington draws attention to his chapters on cycles, and particularly to his ozone and atmospheric electricity hypotheses as especially likely to excite controversy. The attentive reader will probably not disappoint him in this respect, or perhaps the reaction will be one of dissatisfaction more than of controversy. If it is true that cycles of

ozone in the atmosphere are correlated with the reproduction of animals and with human mental activity or that rhythms in atmospheric electricity are related to business and price cycles, this is a discovery of almost incalculable importance. Yet the evidence that such correlations are real does not seem adequate and their interpretation is speculative, without a fully acceptable and demonstrated basis. On some points, at least, strong additional evidence could quite readily be obtained, for instance by further experiments on the physiological effects of ozone and of atmospheric electricity. Presentation of such an extremely important hypothesis without the addition of crucial evidence on it certainly has value and interest, but a feeling of dissatisfaction seems justified, even though the present treatment is only a somewhat popularized summary and some specialized details are to be found elsewhere.

The whole subject of cycles has peculiar and increasing interest. One of the many valuable features of the book under review is that its chapters on cycles, especially Chapters 24-26, are a non-technical treatment, which, regardless of the validity of any particularly hypothesis expressed, provides the general reader with a good introduction to this subject. (The three chapters cited were prepared with the cooperation of E. R. Dewey, Director of the Foundation for the Study of Cycles.)

With its 612 closely-printed text pages, this is a big book and some passages require alert attention to be fully comprehended, but the intelligent reader is likely to follow it with keen pleasure or real fascination. It is full of ideas and of glimpses giving insight into problems that concern all of us. To say that the reader will occasionally want to talk back to the author is only to emphasize again how stimulating and engrossing the book is.

The text is followed by a large bibliography and a good index. There are a number of small typographic errors, but of those noticed the only one that is confusing is in the second line from the bottom of page 47, where "endomorphic" is apparently a misprint for "ectomorphic." GEORGE GAYLORD SIMPSON.

Scientific Societies in the United States; by RALPH G. BATES. Pp. vii, 246; a publication of the Technology Press, Massachusetts Institute of Technology, New York and London, 1945 (John Wiley & Sons, $3.50).—Writing a history of scientific societies requires giving as a background something on the history of science. The author has found the solution of inserting in each of the four principal chapters brief reviews on scientific progress during the period covered by each chapter. These reviews are admirable and serve their purpose despite their extreme brevity. Perhaps more difficult

for the author was to decide where to draw the line separating scientific societies from those of a commercial and industrial character. A fairly large number that would unquestionably belong to these groups have been included on account of the importance of their contributions to the advancement of science.

The development of some of the leading societies has been traced in detail, especially of the American Philosophical Society, the Smithsonian Institution, the National Academy of Sciences, and the American Association for the Advancement of Science.

It was unavoidable that some pages should be filled with long sequences of names of numerous societies. On the whole, however, the book is well balanced and should provide interesting reading to most scientists. Its usefulness as a reference work is enhanced by the extensive Bibliography and Index. With these aids the book provides a wealth of information much of which would otherwise be difficult to locate in the scientific literature. DIRK BROUWER.

ERRATA

"PHYSICAL AXES OF REFERENCES AND GEOMETRICAL AXES OF REFERENCES FOR QUARTZ," by Austin F. Rogers. Vol. 243, July, 1945, pp. 384-392.

p.	line	instead of	should read
384	12	"$\sqrt{3:1}:C$"	"$\sqrt{3}:1:C$"
384	24	"(clockwise)"	"(counter-clockwise)"
384	24	"(counter-clockwise)"	"(clockwise)"
387	29	"mach, Alsatian"	"mach (11), Alsatian"
390	16	"(clockwise)"	"(counter-clockwise)"
390	16	"(counter-clock-)"	"(clock-)"

American Journal of Science
DECEMBER 1945

EMPLACEMENT OF THE UNCLE SAM PORPHYRY, TOMBSTONE DISTRICT, ARIZONA.[1]

JAMES GILLULY.

ABSTRACT. The Uncle Sam porphyry is a quartz-poor latite porphyry whose exposed area is about 20 square miles. Its age is uncertain within wide limits, but is probably early Tertiary. It bears intrusive relations to rocks of the Pinal schist, Naco limestone, Bisbee formation, and Bronco volcanics (which rest unconformably upon the Bisbee formation), and may thus be either of Late Cretaceous or early Tertiary age. It is unconformably overlain by the Gila conglomerate of late Pliocene age. Contact exposures and mine workings indicate that the porphyry is floored near its northeastern border at a relatively shallow depth; its eastern contacts indicate only essentially vertical extension, but the relations are obscured by later faults and by dikes and sills of the porphyry. Most of the other original contacts are concealed, but at the west there are suggestions of a sill form. Observations of internal structures and contacts are consistent with the hypothesis that the intrusive is roughly laccolithic in form and has extended laterally along either a thrust or erosional surface. Petrographically, the rock is distinguished by an unusually fine-grained groundmass—almost vitrophyric over large areas—for so large an intrusive. It is also remarkable for the abundance and wide distribution of inclusions, which are estimated to constitute three to five per cent of the entire body. Local intrusive breccias—some of large volume—contain much higher proportions of inclusions. It is suggested that the fine-grain of the intrusive may be in part due to the chilling effect of these inclusions. Further, it is probable that these are neither stoped blocks nor products of channel abrasion, but are largely fragments of a tectonic breccia formed during the thrust faulting and already available to be picked up by the porphyry magma as it advanced along the surface of a thrust fault. The mildness of the contact effects of the intrusive is attributed to its poverty in volatiles.

INTRODUCTION.

THE Tombstone mining district is in central Cochise County, in the southeastern part of the State. Text Fig. 1. It has been studied by Church (1903), Ransome (1920), and Butler; Wilson, and Rasor (1938). My work, upon which this discussion is based, was done during the winter of 1936-1937

[1] Published by permission of the Director, Geological Survey, U. S. Department of the Interior.

and the spring of 1938. The assistance of Edgar Bowles and Ralph S. Cannon, Jr. is gratefully acknowledged, and the work was further facilitated by a copy of a detailed geologic map of part of the area prepared by F. L. Ransome. Inasmuch as the mines were being studied by Professor Butler and Doctor Wilson at the time of my field work, and it soon became evident upon field check that only very minor changes from Ransome's excellent map could be justified, most of the estimated two

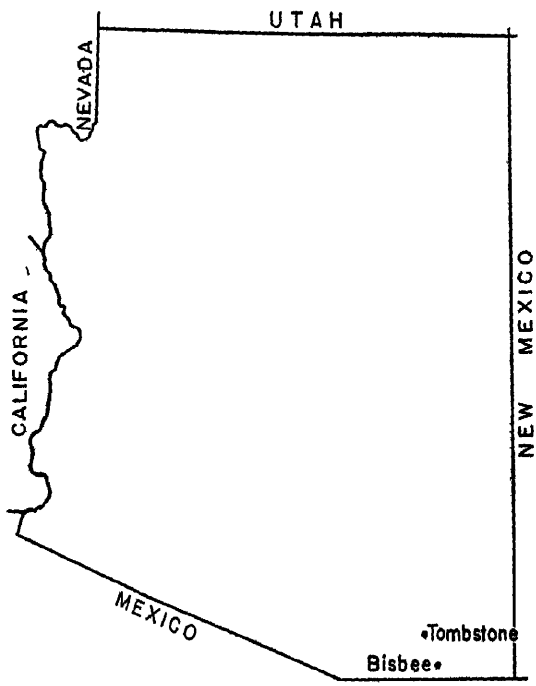

Fig. 1. Index map of Arizona, showing location of Tombstone mining district.

months' field work devoted to the present problem were spent in mapping areas to the south and west of that covered by Ransome, and to making supplementary structural observations within the area of his map. Of the accompanying map, Text Fig. 2, the part within T. 20 S., R. 22 E. is essentially Ransome's the remainder is a product of my own field work and that of my assistants.

GENERAL GEOLOGY.

The principal geological formations in the Tombstone district are the following:

FORMATIONS OF THE TOMBSTONE DISTRICT.

Age		Formation	Thickness, feet
Quaternary		Alluvium	nil to a few score
	unconformity		
Pliocene		Gila conglomerate	several hundred
	unconformity		
Probably early Tertiary		Schieffelin granodiorite Andesite porphyry dikes Uncle Sam porphyry	
	unconformity; possible overthrust faults		
Cretaceous or early Tertiary		Bronco volcanics[2]	5000-6000
	unconformity; possible thrust faults		
Lower Cretaceous		Bisbee formation	3000+
	unconformity		
Pennsylvanian		Naco limestone	4000
Mississippian		Escabrosa limestone	800
Devonian		Martin limestone	320
	unconformity		
Cambrian		Abrigo limestone Bolsa quartzite	800 400
	unconformity		
Pre-Cambrian		Pinal schist	very great

For the purpose of the present paper, the rocks older than the Bisbee formation are sufficiently described by their formal stratigraphic names. The Bisbee formation is represented in the Tombstone area by a series of gray, brown, and red-brown sandstones interfingering with shale and a minor amount of limestone. Locally there is a coarse conglomerate at the base, containing rounded cobbles and pebbles representative of all the Paleozoic rocks, together with schist and several varieties of granitic rock of unknown provenance. There is an important unconformity, both angular and erosional, beneath the Bisbee group in the Bisbee mining district (Ransome, 1904),

[2] The formation here called the Bronco volcanics has not hitherto been given a formal stratigraphic name. It is named from Bronco Hill, in whose neighborhood it is well exposed, and consists dominantly of andesite flow breccias and flows in the lower part and of quartz latite flows and tuffs in the upper There is interfingering of the two varieties of rock; the andesitic rocks constitute about two-thirds of the formation. A more complete description is to appear in a Geological Survey paper in preparation.

about 20 miles to the southeast. Though the structural discordance between Lower Cretaceous and older rocks is not so dramatic at Tombstone as at Bisbee, there can be no doubt that a strong disturbance also occurred here within the same interval, and the conglomerate pebbles record it.

Studies of the country to the northeast, east, and southeast of Tombstone show that there are two systems of thrust faults of post-Bisbee age: one trending northwest, with overriding to the northeast (Ransome, 1904, 1913; Wilson, 1927; Gilluly, 1941), and the other trending east, with overriding to the south. There is some suggestion that the east-trending faults are older than the northwest-trending, but this is dubious and whether any important time interval separates the two groups is still questionable.

It seems clear that the Bronco volcanics are younger than the east-trending thrust faults. It is true that the volcanics are nowhere in contact with faults of this system, but in the area about two miles east of Bronco Hill they rest upon an erosion surface carved across strongly disturbed Bisbee beds. These beds immediately to the south are isoclinally folded along east-trending axes and therefore presumably record the compression elsewhere expressed by the thrust faults of this trend.

The relation of the Bronco volcanics to the northwest-trending thrust faults is not so clear. Only one thrust fault of this trend has been found in the Tombstone area. This fault is exposed for about 2000 feet along the northern spur of The Three Brothers Hill, west of Tombstone, trends about N. 45° W., and brings Naco limestone over strongly disturbed Bisbee beds. The fault dips southwestward at an angle of 20 to 30 degrees. It is cut off in both directions by the intrusive contact of the Uncle Sam porphyry, which is clearly younger than the fault, but there is no evidence as to the age of the fault with respect to the Bronco volcanics. This inconclusive evidence is disappointing as it leaves the question open as to the structural relations of the Bronco volcanics at the time of the intrusion of the Uncle Sam porphyry; i.e., it is unknown whether or not the Bronco volcanics are involved in the thrust faulting of the region. The absence of notable internal deformation of the Bronco cannot be given much weight as evidence of a post-thrust age, for study of other volcanic formations in the Dragoon thrust area shows little sign of deformation in them except immediately along the faults. Accordingly there

are two possibilities as to the local structural conditions prevailing at the time of the intrusion of the Uncle Sam porphyry: if the Bronco is younger than all the thrusts, it rested as a structural unit on an erosion surface carved across the faulted older rocks and the considerable breccia bodies associated with that thrusting; if the Bronco is younger than the east-trending faults and involved in the northwest-trending, it is probable that breccias of at least the younger fault episode were present at the time of the emplacement of the Uncle Sam porphyry. It is clear that the Uncle Sam porphyry is younger than all the strong local deformation except the late normal faults.

UNCLE SAM PORPHYRY.

Name.—The Uncle Sam porphyry was named by Butler, Wilson, and Rasor (1938), from its outcrops on Uncle Sam Hill, about two and one-half miles southwest of Tombstone. They recognized the rock as a quartz latite porphyry and as intrusive. Ransome had called the rock "rhyolite porphyry" but also recognized it as intrusive (Jones and Ransome, 1920). Church referred to the rock as a rhyolite flow (Church, 1903). The rock is clearly intrusive at several contacts and has the composition of a quartz latite, so that the name and interpretation adopted by Butler, Wilson, and Rasor is here followed.

Distribution.—There are four main areas of exposure of the Uncle Sam porphyry. The largest, in the Tombstone Hills, is probably continuous, beneath the alluvium, with the area northwest of Charleston, and possibly both these areas represent portions of a single mass whose most westerly outcrops are those west of the San Pedro River, southwest of Fairbank. The fourth considerable body is that northeast of Bronco Hill; the limits of this mass are completely exposed and any connections it may have had with the larger body to the north must be at depth or have been eroded. Small dikes and sills of the porphyry are found east of the main mass in the Tombstone Hills and as inliers in the alluvium northwest and west of Fairbank. Some of these bodies near Fairbank are also definite sills and dikes.

Contact relations.—The Uncle Sam porphyry is intrusive into the Bronco volcanics, the Bisbee formation, and locally into the Naco limestone at the exposed surface. At Bronco Hill and a point about one and one-half miles to the southeast, it is cut by the Schieffelin granodiorite, but elsewhere its only

contacts with younger rocks are with the valley fill of the San Pedro trough, which rests unconformably upon the eroded surface of the porphyry.

The contact relations of the porphyry are highly variable. At the north spur of The Three Brothers hill, west of Tombstone, the contact dips steeply to the southwest, under the

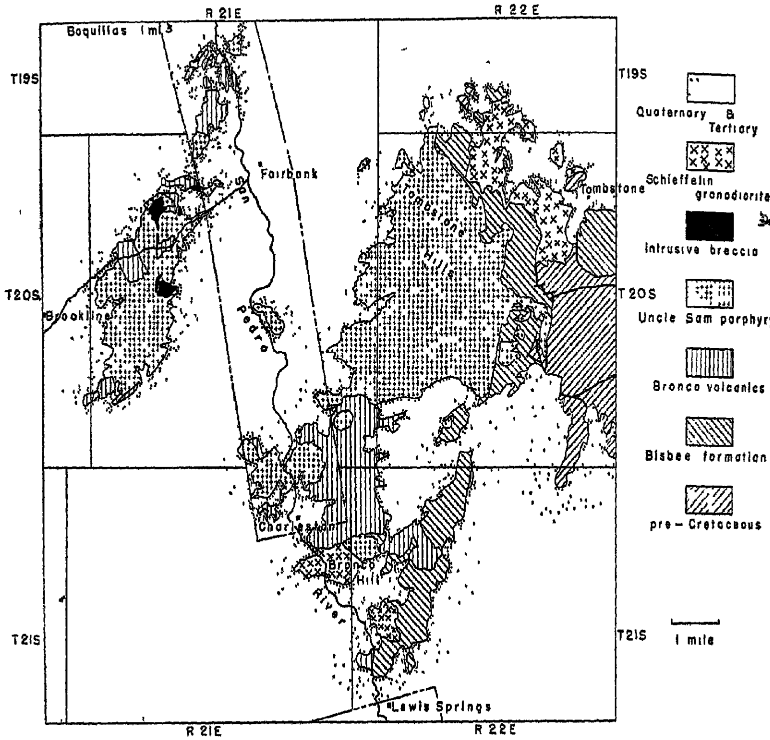

Fig. 2. Map showing distribution of the Uncle Sam porphyry and related rocks. Area near Tombstone largely after a manuscript map of F. L. Ransome. The scale of this map does not permit showing all the places mentioned in the text. They are, however, shown on the Benson Quadrangle of the U. S. Geological Survey's Topographic Atlas.

porphyry. Here the porphyry is in contact with the Naco limestone, which rests on a thrust fault that cuts the underlying Bisbee formation and dips southwestward, toward the porphyry, at angles between 20° and 30°. Just to the southeast the Bisbee formation of the footwall of the fault forms the country rock of the porphyry. From a point near the northwest corner

of sec. 9, T. 20 S., R. 22 E., to the valley of the stream that passes just southeast of the center of the same section, the country rock of the intrusive is a breccia mass that consists of blocks of Naco limestone and conglomerate, sandstone, and mudstone of the Bisbee formation. None of these blocks of sedimentary rock can be followed along the strike for more than a few hundred feet; they are all thoroughly shattered and brecciated internally. Generally the Paleozoic fragments are more abundant near the porphyry contact and those of the Bisbee formation preponderate farther northeast. The breccia is generally sheared and many of the stronger shears dip westward at about 35°, roughly parallel to the contact with the porphyry which overlies it. The porphyry to the southwest shows no comparable brecciation. These relations strongly suggest that the porphyry occupies a thrust plane in this part of its outcrop, at least.

North of Uncle Sam Hill there is a deep salient in which the Bisbee formation floors the valley in such a way as to suggest that it underlies the porphyry at a comparatively shallow depth, as, indeed, has been shown by the workings of the State of Maine Mine, which penetrate a considerable body of shale on the bottom (600 foot-) level of the workings (Butler, Wilson and Rasor), at an elevation of about 4300 feet. This section of the intrusive is therefore probably floored at a comparatively shallow depth, but farther southeast, near the Tombstone-Charleston road, the exposed contact becomes nearly vertical and transects the bedding of the country rock at a high angle. Part of this contact is a post-intrusive fault of high angle. Throughout the area between the Charleston road and the ridge that extends north from Ajax Hill, the porphyry forms highly irregular masses that cut the Bisbee formation without regard to its bedding. An interesting feature of this area is the mass of Uncle Sam porphyry that occupies the major fault which farther north separates the Bisbee formation on the west from the Bolsa quartzite on the east. This fault was undoubtedly formed at the time of the major deformation of the Tombstone district. It had a minimum displacement of 5000 feet and must extend to a very considerable depth. The porphyry that follows this fault is frozen to both walls and has remained entirely undeformed since its emplacement, showing that the intrusion occurred after the major orogeny.

In sec. 25, T. 20 S., R. 21 E., the contact of the main mass

of porphyry and the quartz latite of the Bronco volcanics is steep and transects the volcanics at a high angle, but on the hill that reaches an altitude of 4540 feet in sec. 36, T. 20 S., R. 21 E., the Uncle Sam porphyry seems to have a laccolithic form and the andesitic member of the Bronco volcanics is upturned in a nearly complete ring around it. The same relations prevail in the mass just north of Charleston, though the andesite is not exposed at the surface. Here the quartz latite member of the Bronco volcanics dips away from the porphyry mass on all sides, again suggesting a laccolithic dome.

West of the San Pedro River few contacts of the porphyry, except those contacts with the late Tertiary and Quaternary sedimentary rocks of the valley-fill, are exposed. However, at the south end of the hills southeast of Brookline, the porphyry is in contact with the andesites of the Bronco volcanics. Here the andesite seems to form a conformable sheet between two masses of the Uncle Sam porphyry, or, stated in another way, the porphyry seems to form two sills separated by a thin septum of andesite. Both the bottom of the upper sill and the top of the lower appear to be conformable with the bedding of the andesite and the internal structures of the porphyry seem also to have the same attitude. (See section on inclusions.) The narrow band of Bronco volcanics along the east side of the porphyry mass in SE ¼, sec. 30, T. 20 S., R. 21 E., may represent the footwall of the lower sill, but the actual contact is concealed. The mass of andesite in the northwest ¼ sec. 20, T. 20 S., R. 21 E., appears to be an inclusion in the Uncle Sam porphyry, though it is possibly a part of the roof of the sill, if this form is maintained so far northward.

The Uncle Sam porphyry that abuts the andesite of the Bronco volcanics along the Babocomari River two miles northeast of Brookline seems to rest in general conformity upon the volcanic rock. However, it can hardly be interpreted as the base of a sill because the porphyry crosscuts the bedding of the andesite breccia along the south side of the andesite mass and furthermore the eastern contact dips eastward at about 35° (at a high angle to the bedding), with the porphyry overlying the andesite. This contact has been followed rather closely by a fault, but the fault displacement cannot have been great as there are many narrow dikes of porphyry in the andesite and many large boulders of andesite held as inclusions by the porphyry close to the contact. The small mass of andesite breccia

Fig 1.
Outcrop of nodular-weathering porphyry, south of Brookline The center of each nodule is formed by an inclusion. Knife approximately 4 inches long.

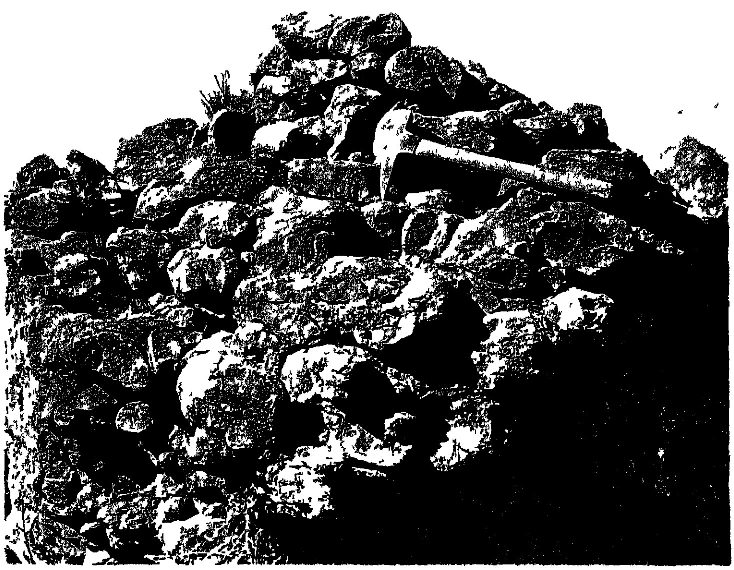

Fig 2.
Another view of nodular-weathering zone south of Brookline. Hammer is 18 inches long.

Fig 1.
A collection of nodules weathered from the Uncle Sam porphyry south of Brookline
An inclusion can be seen in each.

Fig. 2.
Andesite inclusions in Uncle Sam porphyry west of Fairbank.
The specimen is about 8 inches across

of the Bronco that crops out half a mile farther east along the Babocomari is definitely an inclusion, for the contacts are all steep and irregular and the andesite is cut by many dikes of the porphyry.

The Uncle Sam porphyry that crops out west of the San Pedro River northwest of Fairbank apparently forms two intrusive sheets that conform only in the most general way with the structure of the associated Bronco volcanics. The relations are obscured here, but there are innumerable narrow sills of the porphyry along the bedding of the tuffs of the Bronco volcanics and considerable bodies of intrusive breccia, in which the fragments of tuff are strung out and bent by the viscous flow of the injected porphyry.

In the hills about two miles north of Boquillas, north of the area shown in Text Fig. 2, the Uncle Sam porphyry forms roughly sill-like masses that conform in general structure to the major folds of the associated Naco limestone, though they transect the second-order folds.

Intrusive breccia.—There are two areas of intrusive breccia associated with the Uncle Sam porphyry near the Babocomari River, one in sec. 8, T. 20 S., R. 21 E., and the other in sec. 17, a little more than a mile to the south. At the northern locality an intrusive breccia occupies about 100 acres, and is exposed in a topographic amphitheatre, drained by an east-flowing stream. The breccia is fairly well exposed in the stream bed and the walls above it. It consists of a jumble of rocks that range from more than 100 feet in diameter down to microscopic sizes. These rocks have the forms of blocks, boulders, and cobbles and are held in a matrix of Uncle Sam porphyry. Among the rocks included in the breccia can be recognized representatives of the andesite of the Bronco volcanics, both flows and breccias; of the sandstone, mudstone, and conglomerate of the Bisbee formation; and two members of the Naco limestone. These rocks are arranged in the most heterogeneous manner imaginable; limestone against andesite breccia, sandstone against conglomerate, dolomite against mudstone, in an apparently random accumulation. The blocks lie at random attitudes, the bedding in some is vertical, in others, that perhaps abut these, it is horizontal or at any angle between. They are separated from each other by dikes and sills of Uncle Sam porphyry that range in thickness from a fraction of an inch up to several feet. All these dikes and sills show very

strong flow structures and are packed with even more inclusions than are normally contained in the porphyry. There seems to be a slight tendency for the more continuous sheets of the porphyry to lie at low angles and to dip away from the center of the mass in all directions. The normal porphyry overlying the breccia is almost surely domed over the breccia outcrop, as the rather definite boundary of the breccia dips away from the center of the exposure at angles of 10° to 20°. On this interpretation of the structure, a thickness of about 100 feet of the intrusive breccia is exposed here, with no bottom visible. A dike of andesite porphyry cuts across breccia and porphyry and is clearly much younger than both. It is probably not genetically related to these rocks.

Toward the east of this northern breccia mass is an unbroken block of andesite of the Bronco volcanics. It is likewise capped by a low dome (at least in north-south section) of Uncle Sam porphyry. At its eastern edge there is apparently a vertical mass of Uncle Sam porphyry about 100 feet wide that separates this unbroken body of andesite from a smaller mass of breccia like that to the west. The flow-banding in the porphyry overlying the andesite along the creek southeast of the breccia area dips about 50° S., but this steep dip is apparently local and may be due to faulting. Measured normal to these flow structures at least 300 feet of porphyry is exposed above the breccia.

The mass of intrusion breccia exposed to the south, in sec. 20, crops out in a subcircular area of about 70 acres. Here a breccia of sandstone, shale, and mudstone, probably derived from the Bisbee formation, is intimately cut by innumerable dikes and stringers of Uncle Sam porphyry that trend in all directions without apparent system. The porphyry stringers and dikes range from a few inches up to 50 feet in width. They show strong flow structures and are packed with inclusions of sandstone, shale, conglomerate, rhyolite, and a white granitoid rock of unknown age. Some of the inclusions are as much as four feet long but most of them measure only a fraction of an inch in length. Here, again, the overlying, less-contaminated porphyry appears to be domed over the breccia, though the exposures are not quite sufficient to make this certain.

Inclusions.—Some of the larger inclusions have been described in connection with the geological relations of the porphyry, as have the masses of intrusion breccia. However,

inclusions are by no means confined either to these occurrences or to the border zones of the porphyry but are found in great profusion almost everywhere in the mass. They exhibit a great range in size. The largest noted outside of the breccias was 20 x 40 feet, many are as much as five feet across, but the great bulk of them are between a small fraction of an inch and an inch in diameter. They are so abundant in nearly all exposures that a normal hand specimen commonly shows at least one and may show half a dozen such inclusions on its surface. This is true not only near observed contacts where inclusions are commonly more abundant than elsewhere, but also far from any known contacts; for example, along the west slopes of the Tombstone Hills, and east of Brookline, half a mile or more from the nearest outcrops of country rock. In many places the inclusions are so numerous that the porphyry verges on a breccia.

In the areas west of the San Pedro, most of the inclusions are andesite and quartz latite of the Bronco volcanics, though sandstone, shale, and mudstone derived from the Bisbee formation are also abundant and a few fragments of granitic rock occur. In the areas east of the river, the volcanics and Bisbee rocks are abundant, but quartzite, dolomite, and limestone of Paleozoic age and the pre-Cambrian Pinal schist can also be recognized, along with fragments of granitic rock of the same type as that found west of the river. The granitic inclusions seem more abundant east of the river than west of it. Near the contacts there is a definite tendency for the inclusions of the adjacent rock to preponderate, but even here there are many representatives of other formations.

Most of the inclusions are angular and show abrupt boundaries with the porphyry matrix, but a few are round and in hand specimen appear to blend with the porphyry. Most of the inclusions of shale or mudstone are more or less altered to hornfels but the alteration of other rocks is far less conspicuous. Microscopic study shows, however, that many of the andesite inclusions have undergone slight alteration and, especially, mechanical disruption.

As mentioned in an earlier paragraph, the inclusions are generally more abundant near the contacts than elsewhere, though this is not invariably true. Locally such aggregations of inclusions reach extreme proportions and preponderate greatly over the matrix, and form bands that are notably different from the main mass of the porphyry. At the south end

of the hills southeast of Brookline such a layer of inclusion-rich porphyry is well developed at the base of the upper of the two sills there exposed. Here the upper part of the sill is eroded away and the topmost exposures are of normal Uncle Sam porphyry that contains many small inclusions. Toward the base the number and size of the inclusions increases and a layer about thirty feet thick consists of perhaps 10 per cent of inclusions. This layer weathers into peculiar nodular outcrops. The nodules range from a few inches to about 3 feet in diameter, and the center of each is an inclusion. Most of these inclusions are subrounded or subangular and consist of hornblende felsophyric andesite like that which underlies the sill. Around each of the inclusions, which range in size from an inch or so up to about a foot in diameter, the porphyry has a finer selvage and apparently has been quenched. The spheroidal weathering is in part a reflection of the smoothly-flowing curves of the flow-structure of the porphyry matrix, but this can hardly account for the closure of the spheroidal surfaces revealed by the nearly perfectly spheroidal form of the weathered boulders. The round forms emphasized by the weathering look like piles of cannonballs or coarse, rounded boulders and cobbles. See Plate 1, Figs. 1 and 2, Plate 2, Fig. 1. This layer grades downward rather abruptly into a layer that consists overwhelmingly of inclusions—seemingly as much as 60 per cent—and in which the strongly flow-streaked porphyry matrix hardly suffices to separate the inclusions but merely fills the interstices between them. The base of this zone is the base of the sill, and the contact with the underlying andesite breccia (Bronco) dips gently westward in approximate conformity with the bedding of the volcanic breccia.

Bands of similar "cannon-balls" occur at several other places in the hills southeast of Brookline. At one other locality such a band lies at the basal contact of a porphyry sill (in the north center of sec. 30, T. 20 S., R. 21 E.), but in several other localities in secs. 18 and 19 of the same township the nodular-weathering bands are definitely not at the base of the sill, though they may be near the top, which has been eroded away.

Petrography.—The Uncle Sam porphyry is gray to pinkish gray on fresh fractures but weathers to buff and rusty brown hues. The phenocrysts are inconspicuous on weathered surfaces, but crystals of plagioclase, biotite, and subordinate horn-

blende range from about 1 mm. to about 8 mm. in length. Quartz generally forms somewhat smaller and fewer phenocrysts. The groundmass is aphanitic and near the contacts is commonly glassy. Still more surprising, in view of the considerable bulk of the intrusive mass, is the occurrence of only partly devitrified facies hundreds of feet away from any exposed contacts. The inclusions, which are so abundant as almost to be characteristic of the mass, have been mentioned in the preceding section. They commonly have megascopically abrupt boundaries against the porphyry matrix, though there are some that appear to blend into the porphyry and in many places there are dark clots in the porphyry that suggest more completely digested inclusions. The microscope shows, however, that these apparently blending contacts are chiefly due to the mechanical strewing out of included material and not to reaction with the magma.

Under the microscope, the commonest facies of the porphyry is seen to contain phenocrysts of plagioclase, quartz, biotite, and hornblende, in a groundmass of quartz, orthoclase, plagioclase and biotite, or in a glassy base. A few specimens contain orthoclase phenocrysts also. These are cryptoperthitic or definitely perthitic. Commonly the plagioclase is zoned from about An_{43} to An_{30}, but there are exceptional phenocrysts whose cores are near An_{50}. Among the inclusion-rich rocks there are notable variations from these compositions, as is discussed in a subsequent paragraph. Quartz is generally embayed but some of it has modified rhombohedral forms. A few specimens of those studied contain no quartz phenocrysts. The biotite is of the normal brown variety, but much of it has been altered to chlorite. Hornblende is present in but few of the specimens examined though perhaps half of them contain chlorite that is pseudomorphous after it. In the fresh specimens the hornblende is of the common green variety, with extinction angles of 17-18 degrees. A notable feature of the porphyry is the fracture (and strewing out of the resulting fragments) of a large proportion of the phenocrysts.

The groundmass ranges from vitric to microcrystalline, with a maximum grain size of about .04 mm., though more usually the groundmass crystals do not exceed .01 mm. Some specimens collected at points hundreds of feet from exposed contacts are partly glassy, and contain microspherulites of orthoclase. Where determinable, the groundmass plagioclase is near to An_{30}

in composition and is contained, along with chlorite or biotite, in an intergrowth of orthoclase and quartz or glass.

Accessory minerals include magnetite, apatite, zircon, and sphene, but much of the sphene is an alteration product derived from biotite and presumable ilmenite. A few specimens contain rosettes of tourmaline, dichroic in greenish brown and brown. Many of the specimens are mildly altered, with sericite, epidote, and albite developed in the plagioclase crystals, and the mafic minerals altered to chlorite. Calcite is also present in some of the rocks.

The above descriptions apply to most of the Uncle Sam porphyry, which, as mentioned previously, generally contains abundant inclusions. In the small samples of the normal facies afforded by thin sections but few of these inclusions were seen. For this reason, several specimens from parts of the mass unusually rich in inclusions were selected for study. Several of these came from the Tombstone Hills but most were from the hills west of the San Pedro southeast of Brookline.

Most of the inclusions studied under the microscope show sharp boundaries against the porphyry and there is little or no sign of reaction between magma and inclusions. A cloudiness due to an indeterminable fine black dust in many of the feldspars is the only sign of alteration of the minerals of the inclusions. In view of the fact that most of the groundmass of the porphyry is either glassy or very finely crystalline, lack of strong reaction is not surprising. Nevertheless, there is evidence that the mechanical inclusion of the foreign rocks and the strewing out of fragments from them has resulted in a considerable local variation in the composition of the porphyry. The inclusions of andesitic material, probably chiefly derived from the adjacent Bronco volcanics, are especially noteworthy in this regard. In several rocks containing such inclusions small fragments apparently derived from larger ones can be seen arranged in flow patterns away from the larger ones and thus represent a stage in the scattering of xenocrysts through the porphyry. In order to investigate this aspect of the petrology and evaluate the extent of the contamination, the plagioclase of the porphyry was especially studied.

Specimens of the porphyry that contain relatively few inclusions (none seen in the particular thin sections studied) show rather remarkably constant compositions of the plagioclase. As mentioned above, few crystals have cores more anorthitic

than An_{45}, and An_{50} was the extreme noted. In eleven of these rocks the range was only from An_{35} to An_{30}. These determinations were made by immersion methods and examination of thin sections by ordinary methods. For study of the apparently contaminated rocks it seemed desirable to resort to a method by which the composition of an individual crystal could be determined and several such specimens were examined by universal-stage methods. The zonal method of Rittmann, as presented by Chudoba (1932), was used in most of the determinations, but resort was had to the more precise though laborious methods of Nikitin (1936), for grains not favorably oriented for the more rapid determination. The results of this work on individual plagioclase crystals are summarized in the following table.

Anorthite content of individual feldspar grains of the Uncle Sam Porphyry.

Specimen No.	125	255	256	260	261A	261D	283	286	287
	32 h	35 h	50 i	30 i	50 g	32 g	39 g	36 g	33 g
	32 h	37 h	50 i	31 i	52 g	32?g	40 i	38 g	35 g
	32 h	37 h	52 i	30–22zi	52 g	36 g	40 g	38 g	35 g
	32 h	37 h	52 i	37– 8zi	54–42zg	38 g	40 g	38 g	36 g
	33 h	37 h	54 i	25 ± 4 i	55 g	38 g	40 ± 5 i	39 g	37 g
	36 h	38 h	55 i	37–20zi	58 g	45 i	40 ± 5 i	40 g	38 g
	37 h	38 h	55 i	47– 8zi	58 g	55 i	41 i	40 g	39 g
		38 h	55-45zi	36 g	60 g	55 i	41 g	40 g	
		38½h		36 g	65–56zg	55 i	43 g	50 g	
		39 h		38 g	67 g	56 i		50 g	
		43 h		38 g	70–60zg	58 i			
Mean (incl.)	–	–	52	27	–	56	40	–	–
Mean (por.)	32	38		37	57	35	40	41	36

z, zoned crystal; i, crystal definitely part of an inclusion; g, crystal in glassy base; h, crystal in holocrystalline groundmass.

Of the above specimens, Nos. 125 and 255 contain no identifiable inclusions; No. 256 is an andesite inclusion in the rock of No. 255; No. 260 is porphyry with a glassy groundmass that contains an inclusion of granitoid rock, the feldspars of which have the compositions indicated; 261A is largely devitrified andesite in fragments separated by stringers of highly fluidal glass, containing feldspars essentially identical with those of the andesite, and interpreted as xenocrysts freed from the inclusion; 261D, which is part of the same intrusion breccia as 261A, consists of andesite inclusions in more abundant

glassy porphyry; No. 283 is glassy porphyry containing inclusions of quartz latite (Bronco?); Nos. 286 and 287 contain inclusions chiefly of shale, and no feldspars are identifiable in the inclusions. It is somewhat surprising to find that the feldspars in the glassy matrix of No. 261A are wholly those of the andesite inclusion, for, aside from this specimen, the plagioclase of the porphyry, even in glassy facies, is more albitic. Accordingly, one would expect some of the indigenous feldspar of a composition near An_{40-30} to be intermingled with the xenocrysts derived from the andesite, especially as such feldspars are found in the neighboring specimen, No. 261D. Possibly the absence of these primary feldspars from the narrow glassy seams that separate the fragments of andesite in this specimen is due to the constricted passages between the fragments, which perhaps strained out the larger feldspars in the porphyry magma. This explanation seems a bit far-fetched, but no other occurs to me.

It is perhaps significant that all the specimens listed in the table are glassy except for Nos. 125 and 255. The constancy of the composition of the feldspars of these glassy rocks—ranging between An_{43} and An_{30}—is such as to make it seem likely that the two crystals in No. 286 with anorthite content of 50 per cent are xenocrysts from inclusions of andesite, some of which were seen in the neighboring rock. If so, the few crystals seen in the porphyry elsewhere, which have cores as calcic as An_{50}, are probably to be similarly interpreted. In these other rocks in which the groundmass is more largely crystalline, there should have been better opportunity for reaction between xenocrysts and magma than in the glassy facies, with correspondingly more chance for zoning around the nuclei of any xenocrysts that might be present. This, of course, is not a necessary interpretation of these more calcic cores, for the natural evolution of the magma would lead from more anorthitic to more albitic feldspars, and these cores may record an earlier intratelluric stage in the history of the magma. The uniformity of the feldspars in so many specimens, however, suggests that the porphyry magma was rather uniform as emplaced and hence that these more calcic cores may not represent intratelluric feldspars but xenocrysts, a suggestion that is fortified by their sporadic distribution.

Chemical composition.—The following chemical analyses of the Uncle Sam porphyry have been made:

Chemical analyses and norms of the Uncle Sam Porphyry.

Anal	1	2	3	4
SiO_2	66.59	68.16	68.04	67.60
Al_2O_3	16.77	16.07	15.82	16.22
Fe_2O_3	1.94	1.75	2.34	2 01
FeO	1.26	1.15	.84	1.08
MgO	1.04	.90	.80	.91
CaO	2.86	2.61	3.26	2 91
Na_2O	3.66	3.79	3 93	3 79
K_2O	3.77	3.64	3.32	3.58
H_2O+	.98	1.01	.77	92
H_2O-	.21	.25	.37	28
TiO_2	38	.43	.42	.41
P_2O_5	26	16	15	.19
MnO	.11	.11	.07	.10
ZrO_2	n.d.	n.d.	none	..
CO_2	n.d.	n.d.	.14	...
S	n.d.	n.d.	tr	..
NiO	n.d.	n.d.	none	...
BaO	n d.	n d.	06	..
SrO	n d.	n d.	01	..
Li_2O	n.d.	n d.	tr	. .
Cu	n d.	n.d.	tr	..
Zn	n.d.	n.d.	none	.
	99 83	100.03	100.24	100.00

Norm	1	2	3	4
Q	23.88	25.98	24.60	24.72
or	22.24	21.13	19.46	21.13
ab	30.92	31.96	33 54	31.96
an	12.51	11.95	15.29	13.62
C	2.14	1.63	.10	1.12
hy en	2.60	2 20	2.00	2 30
hy fs	.26	.13	.	.
mag	2 78	2.55	1.86	2 55
il	76	.76	.76	76
hem	.	...	.96	32
ap	67	34	.34	34

Symbol:
I″, 4, 2, 3(4) I, 4, 2(3), (3)4
I, 4, 2, 3(4) I″, 4, 2″, 3(4)

1. (Lee C. Peck, analyst) Porphyry from a point about 1500 feet NE of Bronco Hill, in sec. 7, T. 21 S., R. 22 E.
2. (Lee C. Peck, analyst) Porphyry from southernmost exposure on west side of San Pedro River, in sec. 25, T 20 S, R. 20 E.
3. (R. C. Wells, analyst) Porphyry from a point 2½ miles west of Tombstone and ½ mile east of The Dome (Butler, Wilson and Rasor).
4. Mean of analyses 1, 2 and 3.

In view of the fact that each of the two specimens (1 and 2) collected for the present study contains abundant inclusions of shale and granite, respectively, the differences in chemical composition are surprisingly trivial. Evaluation of the quantitative contamination of the quartz-latite magma would be merely guess-work because of the small silica variation shown, and it has not been attempted. The determinable rocks in the inclusions are of such diverse composition—ranging from quartzite to limy shale and from granite to andesite—that it would be practically impossible to obtain a quantitative determination of the extent of contamination in any event. It is perhaps noteworthy that in the area southeast of Brookline, where the exposed wall rocks are andesite, there are abundant inclusions of both granite and quartz latite (resembling the

quartz latite of the Bronco volcanics which elsewhere overlies the bulk of the andesite of that formation).

Internal structural features of the porphyry.—Despite the abundance of inclusions and the prominence of biotite in the Uncle Sam porphyry, flow structures are only locally conspicuous and in many places are impossible to discover despite careful examination. The orientations of such structures as were observed are shown on Text Fig. 3; more careful and systematic

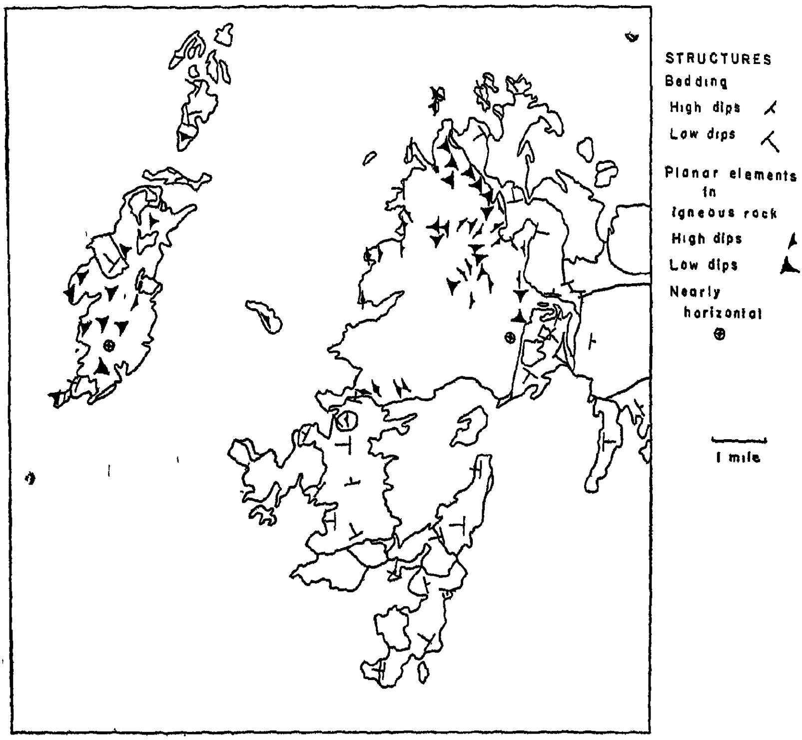

Fig. 3. Structural features of the Uncle Sam porphyry.

examination than was possible during this study might give considerable additional data, but it seems clear from the widely variant attitudes shown that the structural trends recorded by the foliation and by the alignment of inclusions do not correspond very closely to the contacts of the mass. This conclusion was reached also by Ingerson (1939), after a more intensive study of the northeastern part of the mass in the Tombstone Hills. He stated that, "A glance at the projection shows that there is no significant preferred orientation of the platy

inclusions. Even near the contacts there is slight tendency for inclusions to lie parallel to the contact surfaces, there being only 5 out of 21 inclusions measured near contacts that are within 20° of parallel to the contact surfaces. Two of the inclusions stand almost normal to the contacts and two others make angles of over 60°, the average being 40°." He also pointed out that the joints measured in the same part of the intrusive are more or less randomly oriented as to azimuth but that a majority dip at steep angles. Whether the scarcity of low-dipping joints is real or due to difficulties of measurement on gentle slopes is difficult to decide, but as Ingerson correctly points out, the available information on the joints does not indicate any relation to a shallow floor. It might be added that the area studied by Ingerson includes that near the State of Maine mine, in which both surface exposures and mine workings strongly suggest that the floor lies at a rather shallow depth. From this it may be concluded that such features as joints and inclusions are not, in this area, reliable clues to either the proximity or attitude of the contacts.

In the hills southeast of Brookline the zones of inclusion-rich porphyry are rather closely parallel to the exposed contacts and this also is the impression given in the area of the intrusive breccias north of the Babocomari River. In this portion of the intrusive, accordingly, a sill-like form is suggested both by internal structures and contacts.

Emplacement of the Uncle Sam porphyry.—The wide area of younger rocks that separates the main exposures of the porphyry on the two sides of the San Pedro River prevents any decision as to whether these exposures form parts of a single large body or of separate masses. Even if the exposures west of the river belong to a separate intrusive, however, the problem of the emplacement of the porphyry is only slightly less puzzling: the emplacement under cover—even a shallow cover—of a body of igneous rock several hundred and perhaps more than a thousand feet thick and at least three miles in diameter does not normally yield a microcrystalline to vitrophyric rock. How so large a mass could be so quickly quenched is difficult to understand.

That the magma was within its crystallization range when it was emplaced is clear from the similarity in both size and composition of the phenocrysts in the glassy facies with those in the more largely crystalline phases. The considerable frac-

turing of both inclusions and phenocrysts also suggests a high viscosity of the magma. How so highly viscous a magma could incorporate so large a proportion of inclusions and distribute them more or less uniformly through its mass is also difficult to comprehend, as the possibility of turbulent flow seems remote. These anomalous features of the Uncle Sam porphyry are probably connected with its mode of emplacement. It may be recalled that the northeast contact of the main mass in the Tombstone Hills is locally formed by a wide zone of overturned and brecciated beds belonging to the Bisbee formation and the Naco limestone, in which the Naco rests in part upon overturned beds of the Bisbee. The Naco is thrust over the Bisbee on a clean-cut fault at the north end of the Tombstone Hills north of The Three Brothers. The contact along this side of the porphyry dips southwestward beneath the intrusive and Bisbee beds are penetrated beneath it in the State of Maine mine. These relations suggest that the porphyry here occupies a thrust plane; unfortunately not enough of the other contacts are to be seen to establish whether or not this is a general relation. It is clear that the intrusion of the porphyry did not itself cause the overturning of these beds because the intrusive is not itself deformed nor does it have systematic flow structures related to the contacts. This is also the conclusion of Ingerson. Additional evidence that the intrusive is younger than the major deformation of the region is furnished by the dike of Uncle Sam porphyry that occupies, with frozen contacts, one of the major normal faults of the Tombstone district just west of Ajax Hill. This fault is younger than most, if not all, of the folding in this area. Accordingly, it seems reasonable to attribute the relations just discussed to the occupation of a low-angle, west-dipping thrust fault by the porphyry.

If this is true, it seems that the innumerable fragments incorporated in the porphyry need not be attributed to stoping—which would be decidedly unlikely for a magma so near consolidation temperature at the time of emplacement—nor to abrasion of the walls of the conduit. The fragments may reasonably be regarded as breccia along the thrust fault, already comminuted and ready for engulfment when the magma occupied the fault space.

It is by no means intended to imply that the porphyry is limited to a thrust surface. At many places between the

Tombstone-Charleston road and Ajax Hill the porphyry forms irregular dikes and sills and consequently cannot have been governed in detail by a pre-existing fault pattern. Similarly, near Bronco Hill and north of Lewis Springs the assumption of fault control would be gratuitous. However, in neither of these localities are the inclusions so abundant as they are in the main mass, and at least in the southern localities the groundmass of the porphyry is more coarsely crystalline than in the average of the main mass. Unfortunately, the possible significance of this feature was not realized at the time of the field work and collections were not sufficiently extensive to warrant any statement as to details of crystallinity of the minor masses west of Ajax Hill.

The abundance of inclusions of andesite of the Bronco volcanics suggests that the fault breccias postulated as the source of the other inclusions were younger than the Bronco. This is not certain, though, for flow and tuff breccias make up much of the Bronco volcanics. The diversity of the inclusions may perhaps equally well result from incorporation of pre-Bronco thrust breccias and of pyroclastic andesite (Bronco) deposited on them. Thus, even if the suggestion here offered is correct, i.e., that many of the inclusions represent thrust breccia fragments—it does not prove that the thrusts are younger than the Bronco volcanics. It would be reasoning in a circle to cite the abundant andesite fragments as evidence of a post-Bronco thrust, however consonant with such an interpretation they may be.

In the hills west of the San Pedro, contacts with pre-porphyry rocks are even fewer than in the Tombstone Hills. That the intrusive is more or less sheet-like seems indicated by the local relations at the most southerly outcrops, but farther north no contacts with older rocks are found except northwest of Fairbank where the exposures are poor, and far to the northwest, near Boquillas. Near Boquillas the porphyry is generally sill-like, though it sends out a dike for several hundred feet into the upper member of the Naco limestone, which is here the country rock. There is no suggestion of fault control of the intrusive in this northernmost exposure; although the intrusive breccias east of Brookline do not necessarily imply that the porphyry has here incorporated a thrust breccia, they are certainly compatible with such an interpretation. The strong suggestion of a sheet-like form of the breccia and the

apparent conformity of the structure of the porphyry above the largest of these masses, together with the intimate jumbling of blocks of very diverse stratigraphic position, all fit very well with the view that the porphyry here, also, occupies a thrust plane. That such an assumption is compatible with the geologic history of the region is pointed out in the paragraphs dealing with the structure of the area, though there is no direct evidence, owing to the overlap of younger formations, that the thrust faults occur west of the San Pedro River.

A sheet-like form for the larger bodies of Uncle Sam porphyry seems an almost necessary corollary of its fine grain and even vitrophyric texture. If this sheet-like form is conditioned by a pre-existing fault surface or by several of them, a reasonable explanation is afforded for the high content of inclusions of diverse origins. The possibility immediately arises that the inclusions may have contributed to the quick chilling of the intrusion. Although this would almost surely have been their qualitative effect, the quantity of incorporated material hardly seems adequate to accomplish very drastic chilling. Their quantitative effect is discussed in the following paragraphs.

In order to evaluate the temperature effect of the inclusions on the magma, certain assumptions are necessary. These include estimates of the proportions of the inclusions, of the specific heat of inclusions and magma, and of the original temperatures of inclusions and magma at the time of the incorporation. In view of all the uncertainties involved, only estimates can be made for any of these factors. It is here assumed that the specific heat of both magma and inclusions is the same (Daly, 1933).[8] The temperature of the inclusions at the time of their incorporation in the magma can only be guessed at, but if they were picked up near the final resting place of the magma, they were probably not at great depth—perhaps 3000 feet—and with a normal thermal gradient of 1° C. per 100 feet, would have had a temperature not far from 50° C. The temperature of the magma may be assumed as 700°, within the crystallization range of quartz latite magma as estimated by Larsen (1929). These assumptions thus postulate a temperature difference between magma and inclusions at the time of their immersion, of 650°. Inasmuch as the specific heats of

[8] Daly's figures differ slightly for vitreous and solid phases and the specific heats of both are functions of temperature, but as a rough approximation, identical specific heats may be assumed without serious error.

the two can be regarded as the same, the final temperature of the mixture would be related to their initial temperatures inversely as the masses of the material involved.

Let x be the temperature increment of the inclusions, y the temperature decrement of the magma. Then, if the inclusions amount to 3 per cent of the final mixture,

$$3x = 97y$$
$$x + y = 650$$

The solution of these equations gives $y = 19.5°$ as the temperature drop in the magma as a result of the chilling effect of the inclusions. If the inclusions are assumed to amount to 5 per cent of the final rock—an improbably high figure for the mass as a whole—the magma would be cooled 32.5° by their incorporation.

Although these calculations are very rough, and based upon assumptions that may be considerably in error, it seems unlikely that the chilling effect of any reasonable amount of inclusions could have exceeded 50° C. and probably was not more than half that. Little is known of the rates of crystallization of the rock-forming minerals and their variation with temperature, and it may be that a rapid chilling of this seemingly moderate amount might suffice to preserve the glassy or extremely fine-grained groundmass that characterizes the porphyry. However, it seems that this would only be true if the magma as intruded were also unusual in some other respect. The unusual character most likely to have contributed in this way is poverty in fluxes, a poverty that is consistent with the insignificant chemical reaction of the inclusions with the magma and with the slight contact alteration of the country rocks. Accordingly, it is concluded that the unusually fine grain of the groundmass of the Uncle Sam porphyry may be in part a result of the incorporation of the unusual amount of inclusions but that this was probably combined with poverty in volatiles also.

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THE CHALICOTHERES AS A BIOLOGICAL TYPE.

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EXTINCT animals occur in the strata of the earth's crust only as skeletons, often fragmentary. The restoration of an animal on the basis of such remains is a difficult task requiring great erudition in the student. It is still more difficult to write the history of the group to which the animal belonged, and the difficulty increases in proportion to the differences of the extinct animal from animals still living. Extinct animals with skeletons very unlike those of recent animals are often a real enigma.

For a long time when only limb bones of *Chalicotherium* were known, the animal was placed among Edentata because its powerful claws suggest those of a sloth. When other parts of the skeleton were found, *Chalicotherium* was placed among the Ungulata in the Perissodactyla, although it differed from all other fossil and living Ungulata [then known] in having claws, not hoofs.

Holland and Peterson (1913) in their monograph bring together a complete list of literature on chalicotheres for the period of 1825-1913. Their detailed quotations give a good idea of previous knowledge of this group of animals. In following years the Chalicotherioidea continued to be studied chiefly by Americans (e.g. Matthew, 1929; Colbert, 1935a, b). Russian literature on Chalicotherioidea is very small in amount for until lately only a few chalicothere bones had been found in Russia. Quite recently, however, the bones of chalicotheres have been found in large numbers in the Tertiary deposits of the Golodnaya Steppe in Southern Kazakhstan. Here the Lower and Upper Tertiary strata are separated by a layer of conglomerate with abundant bones and teeth of mammals. The great majority of these bones belong to a large chalicothere. It has been possible to assemble an almost complete although composite skeleton, to study its elements in detail, and to come to conclusions about the habits of the animal and its phylogenetic relations (Borissiak, in press).

In the skeleton of chalicotheres (Fig. 1), striking features are the rather long neck, the small skull, the comparatively long and thin fore limbs, and the short, massive hind limbs. The feet were digitigrade and the replacement of hoofs by claws was especially well developed on the fore limbs.

In some species of chalicotheres the skull is long and low (like the skull of the horse), but in other species it is short, resembling, in these instances, the skull of a bear. The skull

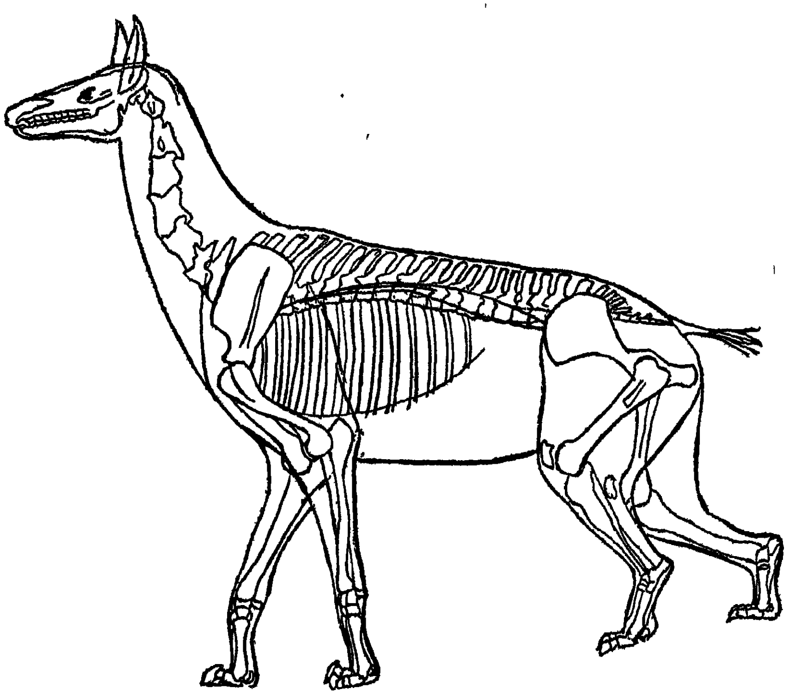

Fig. 1. Restored skeleton of ***Phyllotillon betpakdalensis*** (Flerov) from the Tertiary of the Golodnaya Steppe.

has characters of primitive Perissodactyla (tapirs, early titanotheres) but also a few characters known only in chalicotheres (e.g. two deep impressions on the sides of the presphenoid). The structure of the cervical section of the vertebral column was very peculiar. It was rather long and at the same time very massive, especially in comparison with the small skull. The vertebral centra were reduced relative to the well developed, flattened neural arches, which bore strong zygapophyses. Such

a structure shows that the dorsal muscles of the neck were very strong in comparison with the relatively weak ventral muscles—relations opposite to those observed in typical Perissodactyla.

The structure of the fore limbs, particularly of the manus, was very peculiar and unlike that known in any other mammals. In the most specialized forms, only three of the four digits articulated with the carpus, the fourth and smallest digit being joined to the proximal part of the neighboring digit. The chalicothere carpus was low, with a small, narrow os magnum. The last character distinguishes chalicotheres from horses, the os magnum of which is large, low, and flat, but in this respect chalicotheres are closer to titanotheres. The articulation of the carpus with the fore arm was a transverse arc which per-

Fig. 2. The second digit of the manus of *Phyllotillon betpakdalensis* (Flerov).

mitted considerable swinging of the manus to both sides. Articulation of carpus with metacarpus was very abrupt. On the anterior side of the distal bones of the carpus and on the proximal ends of the metapodials there are rugose swellings for the attachment of strong extensors, while in perissodactyls and in mammals in general limb flexors are usually more strongly developed than extensors. A walking or running animal pushes itself from the ground by flexing its limbs while extensors are used only to bring the limbs to a new place ahead, which is much easier work. The anterior muscles of the chalicothere scapula were also stronger than the posterior. The anterior faces of the metacarpals were evenly convex in all directions, as in some carnivores. The structure of the phalanges was particularly remarkable (Fig. 2). The second digit was stronger than the others (absence of tridactylism). The metacarpal facet of its

first phalanx was not on the proximal end, but had moved to the anterior (or dorsal) face of the bone. In other digits this displacement was not so great; the facets here only cut off the anterior edge of the proximal end of phalanges. In other words, the metacarpal and first phalanx of the second digit were joined together at a right angle, not in a straight line. The first and second phalanges were often coössified. The ungual phalanx, again, met the second phalanx at a right angle. In this way was constructed a strong, flat, triangular claw with only slight movements in its parts. The whole digit was bent twice at right angles, forming a very strong hook. This structure was similar in the other digits but not so well developed as in the second. Separate segments of digits were only slightly movable but the digits as a whole had a wide movement owing to the spherical shape of the distal ends of the metacarpals.

The hind feet had in general the same structure but it was not so well developed as in the fore feet: the metatarsals had no distal swellings; the distal facets were not all spherical in shape; etc. The feet were tridactyl with a long middle digit, the metatarsals were more or less shortened, and the whole specialization of the phalanges was less advanced than in the fore feet. The hind feet were more massive than the fore feet; the calcaneum was low; the astragalus was straight-sided and almost without a neck; etc. On the whole, this is a rare case in which the specialization of fore and hind limbs has gone in different directions.

As in all animals, one group of anatomical characters changed constantly as the result of growing specialization in adaptation to the environment, while other inherited characters did not change and were common to all chalicotheres. The latter show the systematic position of the animals and in this case demonstrate that the closest relationship of the chalicotheres is with the titanotheres.

This relationship is particularly shown by the structure of the teeth of chalicotheres, which is similar to that of early and primitive titanotheres in which the upper molar crowns still had transverse lophs connecting the ectoloph with the lingual tubercles (protocone and hypocone). In the later titanotheres, the upper molars lost their transverse lophs. In chalicotheres the upper molars remained the same with surprising conservativeness. The only difference between the earlier and later forms is that the molars were more hypsodont in the latter. In

their shape the teeth of chalicotheres represent the best developed browsing type. They were not good for hard grasses, much less for food with remnants of soil, such as bulbs, etc., but were exclusively adapted for soft leaves and branches. The cutting sides of the upper and lower molars worked like sharp scissors, while the strong inner tubercules were for grinding branches and leaves. The structure of the skull was also very similar to that of the early hornless titanotheres, although horns were so typical for the later titanotheres. In the skeleton there are also a great many characters suggestive of titanotheres. In spite of the great specialization of the cervical section of the vertebral column of chalicotheres, the atlas had exactly the same shape as in titanotheres. There is a great similarity in the structure of scapula, humerus, radius, and ulna. The structure of carpus and manus is particularly striking. The small, narrow but high magnum, the very peculiar scaphoid with a small, downwardly directed projection, the abrupt articulation of the phalanges with the carpus, the dilated proximal end of the ulna, the arcuate articulation between the fore arm and the manus—all these characters leave no doubt as to the relationship of the two groups, but weigh against any connection with horses, with which chalicotheres have occasionally been compared because of a certain similarity in the shape of their skulls. (In some restorations, chalicotheres were pictured with horse-like heads and long, curly manes.) The femur had a symmetrical vertical trochlea for the patella. There were also a great many resemblances in the bones of the tarsus. In general the chalicothere pes was more like the titanotheres than was the manus, as a result of the greater specialization of the fore limbs than of the hind limbs in chalicotheres. For example, the pes was typically tridactyl while tridactylism was lost in the manus.

The close relationship of chalicotheres with the early members of the titanothere family gives us an example of the application of Cope's law according to which the origin of a new group is usually from the less specialized forms of the old group.

We pass now to consideration of the characters of the skeleton of chalicotheres dependent on adaptation to their living conditions. New characters in the structure of the skeleton did not, of course, become fully developed at once. They are rather little developed in the Eocene chalicotheres of America

and Asia. Even in the Oligocene forms of Europe and Asia they are still not completely expressed.

What were the living conditions that produced such a peculiar structure of the chalicothere skeleton? From the very beginning of the study of chalicotheres many attempts were made to answer this question. The structure of the feet was explained, for example, as an adaptation to digging, to climbing on trees, to catching tree branches in order to bend them to the ground, etc. (Abel, 1920; Gaudry, 1867; Koenigswald, 1932; Matthew, 1929; and others). Some of these ideas, often mutually exclusive, have been abandoned but a few are still accepted.

We have already seen that the neck and fore limbs of chalicotheres had a different structure from typical ungulates. In the neck the strongest muscles were dorsal, which shows that the animal pulled the head and neck upwards and backwards more often than down to the ground. In the fore feet extensors were stronger than flexors, which tells us that the fore feet were used less for walking than for some other work. This brings us to the conclusion that the normal position of the animal was standing on its hind feet while using the fore feet for clinging to the bark of trees when feeding on leaves and tender branches (Fig. 3). The recent goat climbs in this way when hunting after the leaves of large trees. Lifting the fore limbs for such climbing uses the extensors of the whole fore limb from the manus to the scapula. During feeding the head was moved backwards to pick up leaves distant from the trunk of the tree. The small size of the head was favorable for this operation of the neck. Chalicotheres did not embrace the tree trunk with their fore limbs but, in a manner of speaking, walked on the trunk. The manus was particularly well adapted for such "walking." The claw of the second digit was a strong hook which was driven into the bark of the tree more deeply as more pressure was placed on it.[1] Other digits helped the second very effectively, as each of them could change its place on the trunk with ease. Strong extensors not only raised the manus but also made it very stable. The arcuate articulation between the fore arm and the carpus made side movements of the whole manus very easy when the animal was looking for the best place on the trunk.

[1] This principle is used in hooks or hangers that are driven into a wall and support considerable weights.

The structure of the hind limb supplements the preceding picture. During feeding the animal stood on its hind feet only,

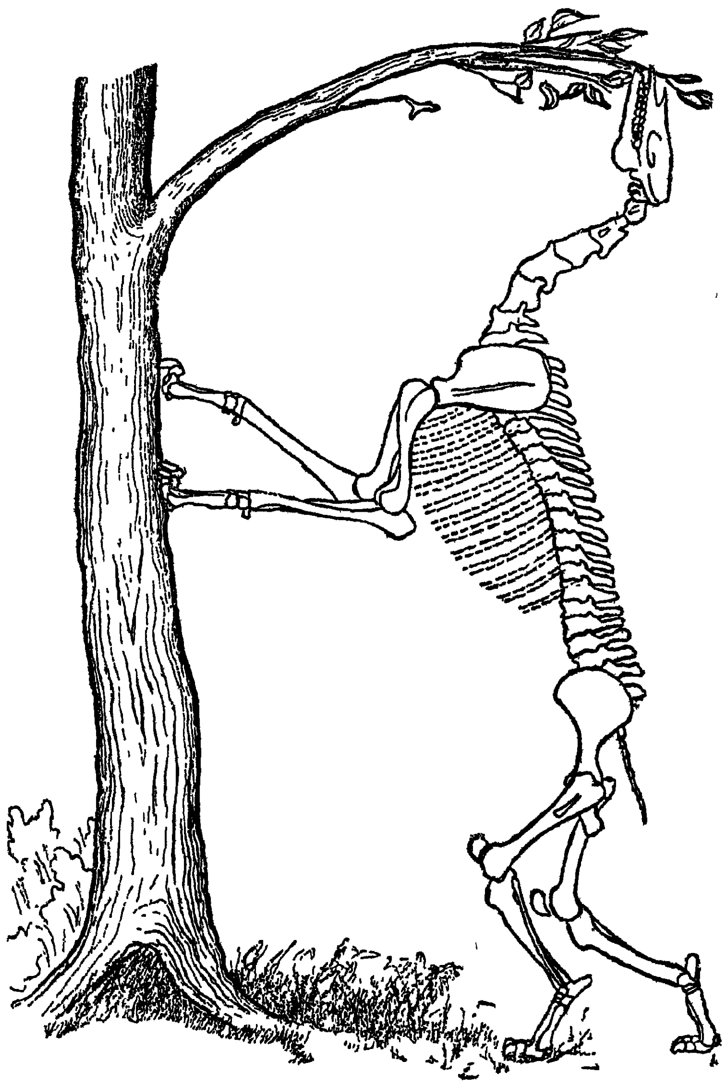

Fig. 3. The posture of the skeleton of *Phyllotillon betpakdalensis* (Flerov) when the animal was feeding.

and these were therefore constructed like the feet of heavy animals and were much heavier than the fore feet. In the forms of later geological age, the hind feet can be compared with the

feet of mastodons for massiveness. The astragalus was flattened and moved on the cuboid, the metatarsals were shortened, and the foot was less specialized than the manus. The claws were not so strong and tridactylism was well developed, while in the manus this development was hindered by the structure of the second digit.

Such is the biological type of the chalicotheres as disclosed by the study of their skeletons. This type arose as an adaptation to the environment. This adaptation is of a different degree in chalicotheres of different geological ages, becoming greater and greater with time.

It has been mentioned in the literature that the biological type of the chalicotheres resembles that of the giraffes. The specialization of the two animals was, however, in different directions. The whole skeleton of the giraffe was specialized for feeding on the leaves on the top of trees and did not progress any further. When the chalicotheres had their fore limbs on the ground, as they certainly sometimes did, they would become normal ungulates. Giraffes live in African savannas with scattered groups of trees. Chalicotheres apparently dwelt in dense forests where they had good protection and no competition because of their high adaptation to this environment. Chalicotheres survived through the whole Tertiary and died out only after that period in spite of their generally primitive inherited organization. Titanotheres, from which chalicotheres arose, had already become extinct in the Oligocene when there appeared the (better adapted) rhinoceroses.

The problem of the study of fossils is primarily a morphoecological analysis of the fossil skeleton. This analysis enables one to distinguish the rather stable inherited characters from those that were the result of adaptation to the environment. The latter characters permit reconstruction of the biological type of an animal and understanding of its ecological relations. This work is, however, only a preparation for another important task of the paleontologist—discovery of the phylogenetic relations of the given form. This can be done by the comparative study of restored representatives of the group. Such a study permits determination of the phylogenetic relationships of each form in reference to the other representatives of the group, in other words discovery of the place of each form in a common genealogical tree.

The peculiar specialization of the chalicotheres developed

gradually. The various representatives of this group, about twenty forms altogether of different geological ages, show different degrees of specialization, which was greater in the forms of later epochs, although we cannot establish an uninterrupted line with gradual modification. On the contrary, practically every form shows some peculiarities comprehension of which is rather difficult, chiefly because the material for study in most cases is very fragmentary. Among these peculiarities is the striking fact that the molar crowns are subquadrate in a few forms but elongated in others. Classification of chalicotheres has generally been based on this character. There have been attempts to bring these variations in the molars into correlation with differences in the structure of the skeletons. Relatively few skeletons are known, however, and associations with the teeth have been only occasionally established. New materials from the Tertiary of the Golodnaya Steppe have showed, however, that all Old World forms are very similar to each other in skeletal structure, whether the molar crowns are short or long. On the other hand, North American forms with long molar crowns, like those of some Asiatic and European forms, have skeletons of quite different type.

It is possible to think of the chalicotheres, after their separation from the titanotheres in the Eocene, as developing further into two separate lines, one in the Old World, and one in the New. Each line developed a number of branches. In Europe there evolved two well defined branches distinguished by the structure of their molars. This is all we positively know on the basis of the present material. Undoubtedly the history of the chalicotheres was much more complicated. A few observations demonstrate that there were subbranches, more especially in the beginning of chalicothere history, which became extinct without leaving any descendants. The genealogical tree of the chalicotheres is composed of several branches, the number of which will increase with discovery of new materials Each branch of the genealogical tree of the chalicotheres represents a distinct direction of their evolution. The place of every form of chalicothere in this tree depends, first, on its pertinence to one or the other of the two main lines (according to which direction of evolution is typical for this form) and, second, on the degree of specialization. Direction and degree of speciali-

zation, like mathematical coördinates, determine the exact place of each form on the corresponding branch. To illustrate these statements we shall bring together information about the best known species of chalicotheres.

The most ancient representative of the Chalicotherioidea is *Eomoropus amarorum*, from the Middle Eocene of Northern America (Osborn, 1913). It was an animal of about the size

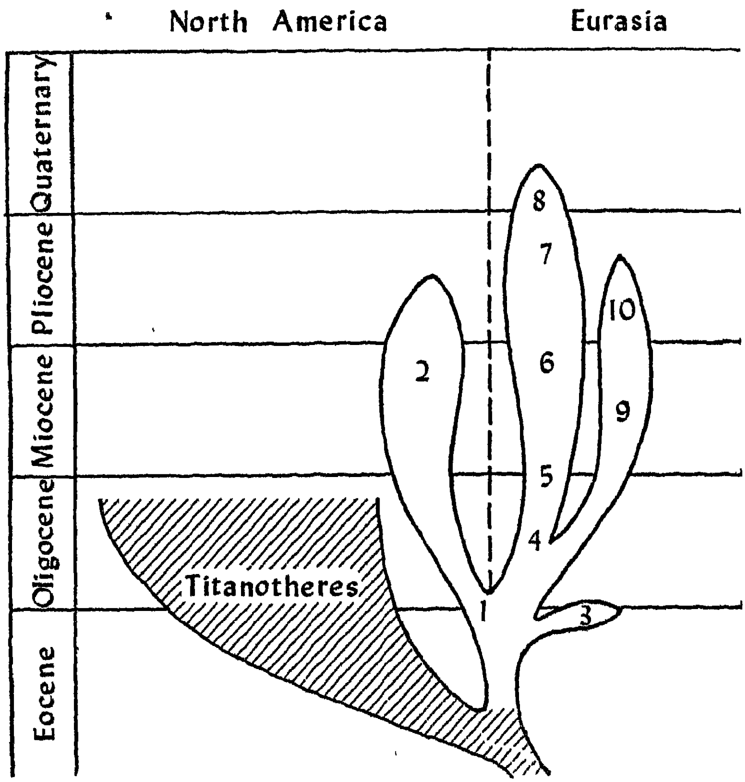

Fig 4. Phylogenetic scheme of the Chalicotherioidea.
1, *Eomoropus.* 2, *Moropus.* 3, *Grangeria.* 4, *Schizotherium.* 5, *Phyllotillon.* 6, *Metaschizotherium.* 7, *Ancylotherium.* 8, *Postschizotherium.* 9, *Chalicotherium.* 10, *Nestoritherium.*

of the sheep with only insignificant specialization: the cervical vertebra did not show noticeable alterations but the metacarpals had already changed typically for the group in their general shape and joint structure, although they did not yet have callous swellings on the anterior side of the proximal ends. The specialization of the hind feet was still less advanced.

From the Asiatic Eocene isolated teeth are known about which it is not possible to say anything definite. They might belong to *Eomoropus* or to some new genus. At the end of Eocene in Mongolia lived *Grangeria*, a very peculiar form in the structure of its dental apparatus and limbs. *Grangeria* represented an early and short-lived side branch of chalicotheres.

In the Oligocene the European line is represented by several poorly known species of *Schizotherium*, still small animals. A few forms (*S. modicum*) had long molar crowns. The separation of the Chalicotherioidea into those with short and those with long molars had thus begun at this time.

At the end of the Oligocene or beginning of the Miocene in Middle and Southern Asia there lived large chalicotheres with long molars belonging to the genus *Phyllotillon* (Pilgrim, 1912). To this genus belongs *P. betpakdalensis* (See Borissiak, in press; Flerov, 1938), from the Golodnaya Steppe. Owing to the abundant material it is one of the best known chalicotheres. The specialized structure of the skeleton of *P. betpakdalensis* has already been described above. A few bones of *S. turgaicum* from the Middle Miocene of Turgai show remarkable similarity to the bones from the Golodnaya Steppe, but belong to an animal of a smaller size. In this case we have forms of the same branch but with different degrees of specialization determining their respective places on the branch. Another species of *Phyllotillon* lived simultaneously in the valley of the Indus River (Pilgrim, 1912).

In the Miocene also, but a little later than *Phyllotillon betpakdalensis*, there lived in North America *Moropus elatus* (see Holland and Peterson, 1913), a species with long molars very similar to those of *Phyllotillon* and similar also in degree of specialization, but different in the structure of various parts of the skeleton. *Moropus* is a representative of the American chalicothere line.

In the Miocene of Europe lived *Macrotherium*, known from fairly complete fossil remains. *Macrotherium* represents the short-molar branch of Eurasiatic chalicotheres. In spite of its short molars, *Macrotherium* was closer in skeletal structure to *Phyllotillon* than to the American *Moropus* with its long teeth. *Macrotherium* and *Phyllotillon* thus belonged to the same European trunk although to different branches.

In the Pliocene both branches of the European trunk were

represented by the largest species of chalicotheres. The form with long teeth is *Ancylotherium* found in the Pikermi Fauna of Greece (Gaudry, 1867). Its hind limbs resemble the limbs of a mastodon in massiveness. The Quaternary representative, *Postschizotherium*, of the same trunk had very strongly developed hypsodont teeth. The branch with short molars was also represented in the Pliocene and Quaternary by big animals.

Such is the history of the chalicotheres as far as it can be represented at the present time. Remains of chalicotheres are still very scarce and it is therefore impossible to make a complete genealogical tree with all branches and subbranches. Altogether we know about fifteen forms which can be placed at different points along a few branches. The task of the paleontologist is to find the position of these points on the branches on the basis of the coördinates as worked out above, and in this way to establish the phylogenetic relationships of the known forms.

We have, however, no basis for connecting these points by lines. This would give the idea of the direct descent of one form from another, which as a rule cannot be proved. In only one case is it possible to show with certainty the pertinence of two forms of different specialization to the same branch. This refers to *Schizotherium turgaicum* and *Phyllotillon betpakdalensis*. This does not mean, however, that one of these forms developed directly from the other and that the two can be connected by a straight line. We prefer to represent the branches as elongated leaves, on which are shown the different forms of chalicotheres according to their mutual relationships.

The study of chalicotheres shows us what paleontology can do for the history of the organic world. We can establish the ecological characters of animals and reconstruct the whole animals. The study of the genera of chalicotheres permits establishment of their phylogenetic relations.

Fossil remains are not complete and paleontology alone cannot decipher the complete history of animals and plants. It needs support from the other biological sciences dealing with recent organisms. But since paleontology alone has all the historical data, its conclusions check the deductions of other biological sciences.

Paleontology has not, however, said its last word. It still lags behind other biological sciences. Not only before but even since Darwin it has usually been in the service of geology,

which has always made special demands for paleontological data. Only now are the possibilities of paleontology for the elucidation of many biological problems becoming clear. In the achievement of independence from geology and in becoming a great biological science, Soviet paleontology occupies a leading position.

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NEOTYPES.

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ABSTRACT. Proposed by Cossmann in 1896, the term and concept "neotype" fill a real need, especially in paleontology, but they have not been well defined or brought into harmony with modern taxonomic methods. Among various uses in the literature, most consider a neotype as a specific basis and standard substituted for a lost type, or sometimes substituted for an unidentifiable type. It is proposed to define neotypes as substitute name-bearers, with no other use or justification in taxonomy. The most important condition making a neotype advisable is not loss of a type, but inability (for any reason) to place a type in one and only one specific hypodigm. Other general conditions are that the neotype should be exactly identifiable, that it should be impossible to demonstrate that type and neotype belong in different hypodigms, and that the use of a neotype should, in each case, promote stability of nomenclature

INTRODUCTION.

EVERY active taxonomist has encountered cases in which the type of a species does not satisfactorily perform the functions of such types, whatever the individual worker may conceive these functions to be. The natural impulse in such cases is to turn to other specimens and to relegate to them the duties for which the type fails. Whether or not they are formally designated as such, substitute types thus tend to enter into taxonomy. This is particularly likely to occur in fields like paleontology, particularly vertebrate paleontology in which much taxonomic work must be based on relatively fragmentary parts of animals, but it can happen in any branch of zoology or botany. This practical need has led to the definition and use of neotypes, which are substitute types proposed for certain purposes and under certain conditions.

There is, however, no general understanding as to exactly what purposes neotypes are to serve and what conditions permit their use. The International Rules do not discuss type specimens and say nothing of neotypes, either permissive or prohibitive. There is no accepted code for specific types, only a body of usage and precedent that is frequently vague and nowhere more so than as regards neotypes. Authoritative definitions of neotypes do not entirely agree and are inadequate. Moreover all take for granted that neotypes, like other sorts of types in a broad sense, are in some way the basis for species,

materials on which species are mainly founded, defined, and compared, in contrast with other specimens also belonging to the species. I have elsewhere pointed out that this assumption is not acceptable in modern taxonomy, and there suggested that the neotype concept also requires revision from this point of view (Simpson, 1940, 424). The present paper is a discussion of this concept and a proposal for its revision and modernization.

PREVIOUS USAGE.

The history and the usage of neotypes are best indicated by citation of their original proposal and of a few subsequent definitions by recognized authorities.

Neotypes ("néo-types") were first proposed by Cossmann (1896, 2-4). He remarked that he first wrote "post-type" but abandoned this word because of its hybrid origin (Latin-Greek). Two quite different and, from a later point of view, conflicting definitions were given. The first applies to type species of genera, is invalid under the present International Rules, was later abandoned by Cossmann himself, and has no present significance or interest. Cossmann's second definition (or discussion, not formally a definition) applies to type specimens of species and is pertinent to the present subject:

"Comme le type d'une espèce est un échantillon unique, qui a servi de modèle à la description et à la figure de cette espèce, il ne peut y avoir d'utilité à le remplacer par un néo-type, que si cet original a été détruit ou a disparu pour une raison quelconque; mais encore faut-il, pour qu'on puisse admettre cette substitution, qu'il soit bien démontré que le nouvel échantillon représente absolument la forme typique que l'auteur avait en vue quand il a créé l'espèce, quelque défectueuse ou insuffisante que soit la figure qu'il en a donnée: on n'a guère cette garantie que si ce nouvel échantillon provient de la même localité, exactement au même niveau, surtout s'il fait partie de la même récolte, quelquefois si c'est un échantillon meilleur, montrant mieux les caractères spécifiques, par suite de son état de conservation."

Schuchert and Buckman (1905, 900) wrote:

"*Neotype* . . . A specimen identified with an already described and named species, selected to be the standard of reference in cases when the proterotypes are lost, destroyed or too imperfect for determination, such specimen being from the same

locality and horizon as the holotype or lectotype of the original species." The words "or too imperfect for determination" constitute an emendation of Cossmann's usage and Schuchert (1905, 13-14) still more explicitly pointed out the nature of this emendation and the necessity for it in dealing with fossil vertebrates and plants. He then defined a neotype as "a supplementary type selected by an author, on which a species is to rest because of the loss of the original type or where the original material still extant is so poor or fragmentary that from it the characters of the species cannot be determined with certainty."

Howell (1929, 219), gave this definition: "*Neotype.*—A specimen selected *to take the place of an original* type of a species or subspecies *when the original type has been lost.* A neotype may be either a *neoholotype* or a *neocotype.*" On an earlier page of the same committee report (218) the preferable (because not hybrid) term "neosyntype" appears, and Plummer & Howell (1932, 266) later proposed the term "neoparatype." Granting acceptance of the neotype concept and its definition in any form, the meaning of these and of a large number of other possible combinations with "neo-" are obvious and they are not further discussed in this paper. I believe all of them, except neotype itself, to be quite unnecessary and unjustified at the present time.

Frizzell (1933, 658), gave an exhaustive review of type terminology, including this statement: "*Neotype* . . . —a later selected type of a species necessitated by loss of the original type material; the neotype must come from the original locality. Although 'neotype' is preoccupied[1] its usage seems so well understood that less confusion would result from the continuation of the term than from its rejection."

Schenk and McMasters (1936, 7 and 8) defined a "neotype" as "a specimen selected to replace the holotype, in case all type material of a species is lost or destroyed." Since these authors use type in the broadest sense and not as synonymous with "holotype," the expression "all type material" in this definition would seem to make the requirement that all identified specimens

[1] Frizzell does not state the grounds for preoccupation. I cannot find any use of the term before 1896, and Cossmann's usage for generic types cannot preoccupy that for specific types. They were published at the same time and were considered by Cossmann to be different applications of the same concept. Cossmann later restricted the definition to include only specific types, an emendation such as is common in scientific terminology and cannot be taken to invalidate the term.

must be lost before a neotype is selected, which probably was not intended. "Primary type material" is meant, as is clear from brief discussion on the next page. It is not clear, however, whether these authors are suggesting that a neotype is to be selected only in the absence of any primary type or whether paratypes are excepted. In the former case, their usage is an important emendation; in the latter case, it agrees with Howell.

Type specimens are nowhere discussed in the International Rules of Zoological Nomenclature and such "rules" regarding them as are published in various commentaries and opinions do not have legal force. As far as the International Rules are concerned, it is not even required that a species should have a type. This is, of course, universally accepted and required outside the Rules and is included in some of the opinions of the International Commission, but (as far as I can find) without amounting to an explicit amendment of the Rules to that effect. The most pertinent opinion of the Commission, as far as neotypes are concerned, is No. 126 (1936) which includes this statement: "If the diagnosis is held to be inadequate, the publication of the name will not prevent any author from subsequent description and establishment under the same name of the same species (as recognized from the holotype, if any); further, if the holotype be wanting or undecipherable, subsequent description and establishment under the same name of a species from the same locality and horizon is permissible. In both these cases the date for purposes of priority shall be the later date, and if the later author (say Brown) is not the same as the earlier author (say Green) then the name shall be quoted as 'Brown ex Green.' If, however, the holotype attached from the beginning to the earlier use of the name with inadequate diagnosis be clearly of a different species from the holotype attached to the later use, then the later use is a homonym as defined in Article 35 and is to be rejected." This Opinion was adopted by unanimous vote of 14 Commissioners, 5 abstaining but none dissenting. One member, (Stone), concurring in the Opinion as a whole, commented that the passage quoted above "is so far reaching that it should be definitely embodied in the Rules rather than be considered in an opinion on a single case."

This opinion essentially validates the neotype procedure in its most radical form, not only for cases of loss of the type but also when the type is known but unidentifiable. Its approach

is different, since it apparently assumes that the later author is for nomenclatural purposes creating a new species or specific name with a new type ("holotype") and that the identity of name with an older published name does not create homonymy because the name is not shown to be applied to a different species. This somewhat tortuous legal reasoning seems to be rather beside the point, and most authors would prefer to distinguish the two types clearly, one as type (or "holotype") and one as neotype. The important point is that this opinion provides authority for the procedure without specifically prohibiting the terminology here, and I think generally, preferred.[2]

In 1935 Frizzell and Wheeler outlined a case in which application of the neotype procedure would be considered legitimate by almost anyone who admits the procedure at all, and they proposed submission of the case with the request to authorize neotypes to the International Commission. The pertinent Opinion No. 126 had not then been published and was evidently unknown to Frizzell and Wheeler. As far as I can learn, no opinion has yet been given in the case submitted by them. In any case, the real situation is that the Commission has no power either to authorize or to reject neotypes.

DEFINITION.

In the quotations given above and in the literature generally, neotypes are defined as much by the author's opinion as to why and when they are to be used as by a statement as to what they are. It may clarify discussion if these three factors are considered separately, first defining the general concept of neotypes, then considering their purpose and finally the conditions under which they are desirable or warranted.

In the old inclusive sense (to which I do not now subscribe)

[2] This provision of authority is important, as involving a well-considered opinion widely recognized and available to all, and it may quiet qualms as to following a procedure not specifically included in the Rules. The legal position, under these Rules, is nevertheless equivocal since in themselves they do not authorize the Commission to change the Rules or, as here, to supplement them. The Commission is authorized only to suspend the Rules in given cases. Thus (as Stone pointed out) the generalization included in Opinion 126 (like various others in the Opinions) does not in any way become part of the Rules, and it is not binding on those who follow the Rules. For this reason it is still correct that the Rules have no bearing, one way or the other, on the neotype procedure, which is extra-legal and remains subject to personal opinion, agreement, and consensus.

types are customarily divided into primary and secondary. Primary types are used in the original proposal of a species and are basic for it. Secondary types are used in subsequent study to supplement knowledge of a species. As the term has always been used, and despite marked differences in other respects, a neotype does not strictly belong to either category: it is in some sense basic, like a primary type, but it is subsequent to the original publication, like a secondary type. It is not one of the original types, but it is intended more as a substitute than a supplement. Avoiding disputed questions as to purpose and permissibility, the following definition includes all previous uses of the term:

Neotype.—A specimen explicitly designated in a publication subsequent to the original publication of a named species or subspecies and proposed as a substitute for the original type or types.

PURPOSE.

Published statements are seldom explicit as to the purpose of neotypes, but some purpose is always implicit and is usually considered by the author to be self-evident. In previous usage two different and sometimes conflicting general purposes have been involved: to provide a better basis and standard of comparison for a species the type of which is not available or is inadequate, and to fix the meaning of a name attached to a type that, for some reason, is not exactly identifiable.

Cossmann's original proposal says nothing as to purpose, but he apparently had more in mind the first of these two purposes. He says that it must be well demonstrated that the neotype represents absolutely the typical form that the author had in mind when he created the species, i.e., that it is certainly of the same species (or subspecies) as the type. Obviously this condition can never be met if there is serious doubt as to the identification of the type. As originally proposed, then, a neotype was intended mainly as a standard of comparison replacing the original standard. It was not considered necessary for it to be more exactly identifiable than the type, as is further shown by Cossmann's statement that it may sometimes (and hence does not always) show the specific characters better than does the type.

This is historically the original use of the term "neotype,"

but there has been a tendency to change the primary purpose. Thus by including the situation where the type is too imperfect for determination among the conditions for proposal of neotypes, Schuchert and Buckman introduced a new idea as to purpose: to make a species definable when it was not so on the basis of the original type material. Few later workers have explicitly stated this purpose, but it is evident that many of them have had it in mind.

The difficulties and confusion involved in this mixed concept of the purposes of types in general have been discussed elsewhere (Simpson, 1940). It is there pointed out that types in the usual sense do not well or properly serve as bases for species or as standards of comparison and it is proposed to restrict the type concept to specimens used solely as name-bearers.

These considerations apply with full force to neotypes and the result of the multiple purposes involved in previous usage is that no purpose is adequately served. It seems desirable to restrict neotypes to some one purpose. Although he does not mention neotypes, the proposal by Troxell (1921, 475-476) of the term "protype" is essentially such a redefinition of the neotype concept. A protype excludes the purpose of substitute name-bearing. Indeed Troxell suggests that a protype bear a specific name different from that attached to the type that it supplants, a proposal so contrary to taxonomic rules and procedure that it has never been adopted, even by Troxell, himself. The term protype was intended to apply to a relatively complete specimen of a species previously known only from a fragment. If a neotype were considered only as a new and better basis for definition and comparison, "neotype and "protype" would be essentially synonymous terms. A relatively good specimen used to redefine a species could then be designated a neotype, regardless of the availability or identifiability of the type. This would be one of two permissible restrictions and redefinitions of neotypes, a usage that is historically just as valid as the other and that has occasionally been adopted without explicit redefinition.

If, however, this definition were adopted, neotypes would be restricted to a purpose previously assigned to types but one that they cannot serve in good modern taxonomy. It is proposed to deny all such purpose to types and to discard all type terms and concepts that are useful only from this point of view.

Neotypes would then be discarded along with hypotypes, holo-paralectotypes, homoeotypes, ideotypes, and dozens of others. Since protypes are essentially neotypes restricted in this way, it follows that they have no place among modern type concepts and terminology.

The other possible restriction of neotypes is to exclude all thought of basis for definition or comparison and to retain the idea of substitute name-bearing. This is a proper type concept, as I now understand it, and would make neotypes acceptable in nomenclatural procedure. Such restriction is admittedly a radical emendation of Cossmann's original proposal and of current usage, but it is a logical development, the only alternative to which would be the unnecessary and undesirable proposal of a new term for neotypes in this restricted sense.

The following definition from the point of view of purpose is therefore proposed:

Neotype.—A specimen attached to a previously published specific or subspecific name to serve as its name-bearer in substitution for the type.

PERMISSIBILITY AND ADVISABILITY.

All previous definitions of neotypes have included some statement of the conditions under which their use was proposed or of opinion as to their permissibility. The conditions originally set by Cossmann were:

1. The type is destroyed or has disappeared.
2. The neotype represents absolutely the same typical form as the type, and in further guarantee of this:
    a. It comes from the same locality and exactly the same level.
    b. Preferably [but not necessarily] it was collected at the same time,
3. Sometimes [not necessarily] the neotype is a better specimen than the type, so preserved as to show the specific characters more clearly.

Later authors usually make no requirement that the neotype be demonstrably of absolutely the same form (species or subspecies) as the type, because they often imply that the type is not exactly identifiable, but they do almost invariably insist that there be some probability that they are the same form and

therefore require some community of origin. The destruction or loss of the type is always recognized as permitting the designation of a neotype, and it is always taken for granted, although seldom stated, that the neotype must be exactly identifiable, as a corollary of which it is usually implied although not set as a condition that it should be a more complete specimen than the type. Later authors also frequently imply but seldom state the condition that the type is not exactly identifiable. This may be for later authors but was not for Cossmann the primary idea back of the condition of loss of the type. Schuchert and Buckman added the alternative, a logical development of this idea, that neotypes may also be proposed when the type is not lost but is unidentifiable.

Several of the most recent definitions make no condition except that the type be lost. Thus for Schenk and McMasters (1936, 8) this situation is not merely permissive but also compulsive: "When the original type material of a species is lost, the reviser of the species should choose a neotype."

The definition of neotypes here proposed makes all these various sets of conditions unsatisfactory, since all are either inadequate or, from this newer point of view, illogical. The following seem to me to be the general conditions under which neotypes, as substitute name-bearers, are useful and may properly be proposed:

1. The type or all the syntypes of a species or subspecies cannot be placed with reasonable probability in one and only one hypodigm.[3]

2. A specimen available as neotype can be placed in one and only one hypodigm.

3. There is no known reason why type and neotype should not belong to one hypodigm and no reasonable possibility that they can be shown to belong to different hypodigms.

4. The proposal of a neotype will promote stability and clarity of nomenclature.

Each of these conditions involves certain secondary and limiting considerations to be briefly discussed.

1. When a type was considered primarily as a standard of comparison it was reasonable to feel that its loss, regardless of other circumstances, warranted setting up a substitute standard. It was also logical on this basis, although some

[3] Term defined in Simpson (1940, 418).

students who accepted these premises did not accept this conclusion, that an imperfect type, limited as a means of comparison, should be supplanted by one relatively perfect and offering a wider basis for comparison. If, however, a type is only a name-bearer, its loss or its imperfection have no direct bearing on the desirability of a substitute. Then a neotype is needed only if the loss or imperfections prevent the adequate functioning of the type as a name-bearer, which is not necessarily the case. On the other hand, even a relatively good type and one that is not lost may occasionally break down as a name-bearer and need replacement by a neotype.

Available descriptions, records, illustrations, or reproductions of a lost type may be and usually are sufficient to place it in one hypodigm. If this is true, the type, although lost, is still a sufficient name-bearer and no neotype is needed or justified. It is universally assumed that loss or destruction of a type specimen does not mean that it ceases to be the type. But it may happen that knowledge of a lost type is inadequate or that the type, itself, is inadequate to obtain the data diagnostic of a single current hypodigm, and then the substitution of a neotype may be useful. It can even happen, especially for recent subspecies, that a perfect specimen is not exactly placeable unless its precise origin is known, and then the absence of adequate field data may warrant designation of a neotype for which such data are available.

2. Obviously a neotype serves no purpose unless it is exactly identifiable. The need for neotypes arises when subsequent discovery reveals closely allied species that are distinguished by characters not then observable in the type. In proposing a neotype, it is therefore important as far as possible to guard against the rise of the same situation with regard to it, necessitating its own replacement by a second neotype. No one has enough prescience to guard against this with complete certainty, but a safe general rule is to require that a neotype show most or all of the characters customarily used in the taxonomy of its group and of allied groups. Like a type, and still more stringently, a neotype should be the best specimen available and should have as complete field data as possible.

3. *If it can be demonstrated that type and neotype belong to one hypodigm*, a requirement explicit in Cossmann's proposal

and implicit in some later work, *there is no need for a neotype* on nomenclatural grounds. Thus the proposed modification of this requirement is negative: it must be very improbable or practically impossible to demonstrate that type and neotype belong to different hypodigms.

The greatest danger of the neotype procedure and a reason for avoiding it except under certain limited conditions is that a type may later prove to be placeable in a hypodigm different from that of the neotype. Then the result of the proposal of the latter will have been to confuse nomenclature and render it unstable. This situation is most likely to arise when types are lost and later found, a history that is not uncommon. Instead of considering the loss of the type as the sole or essential condition for proposal of a neotype, as in most previous work, I therefore maintain that *proposal of a neotype for a lost type requires more hesitation than if the type were not lost.* Only with the specimen in hand or in the rare cases where it has surely been destroyed can a definite conclusion be reached as to its lack of identifiability.

The use of a neotype invoves the philosophical conviction or the technical fiction that it really does belong to the same species or subspecies as the type. This is really only a fiction or even a metaphysical consideration under the proposed condition that a neotype be used only when the specific or subspecific attribution of the type cannot be established. Yet the fiction is necessary and can only be maintained if there is some likelihood that it is in agreement with an indeterminable truth, a likelihood supported by insisting that the type and neotype have the same origin. From a more practical point of view, this insistence is important in reducing the risk that a type may turn out, after all, to be demonstrably different from its neotype.

Two specimens are seldom from exactly the same locality or, if they are fossils, horizon. It is necessary to allow some latitude in this requirement for neotypes. The safe rule would seem to be that the known difference in provenience between type and neotype should be less than the minimum range for subspecies in the group to which they belong. Some subspecies range horizontally for thousands of square miles or vertically through hundreds of feet of strata. Others are known only from a few square yards or from a stratum a fraction of a foot

in thickness. Obviously the allowable difference in origin between type and neotype is quite different in the two cases.

4. The principal reason for having types of any sort is to standardize and stabilize nomenclature. Sometimes neotypes tend to this end, and then they are needed. Sometimes they do not promote this aim, and then they are useless if not positively harmful. The neotype procedure lends itself particularly well to the preservation or revival of old or forgotten names. Other things being equal, this is not an unworthy aim, but the use of nomenclature for its historic value, or to give honor or to maximate egos, is properly a secondary consideration. The cardinal principle is to keep nomenclature as a precise, concise, and comprehensible means of recording and communicating taxonomic concepts. Each individual case requires separate judgment as to whether the proposal of a neotype is in accord with this principle. There are, however, a few particularly common general situations in which the use of neotypes is likely to be considered:

A species is found and named. Later the group to which it belongs is found to include various different species. The earliest specific name is applied to one of these and the others receive different names. Eventually a reviser discovers that the type to which the earliest specific name is technically attached could, whether because of loss or of inadequacy, be placed about equally well in any of two or more of his specific hypodigms. By attaching the name to a neotype that does definitely belong in the hypodigm of the species currently called by the name, he can fix the names with generally accepted and understood meanings. This is surely a desirable result, and I know no other acceptable procedure for reaching it. The problem is insoluble under the International Rules and so an extra-legal procedure that is not illegal seems entirely justified. Such cases are the principal occasions for using neotypes and the best justification for them.

Another common situation is one in which the earliest specific name, based on a poor type, is virtually forgotten and the well-established species of the group are all best known by other, later names with well identifiable types. If a reviser finds that he can definitely place the old type in one of his specific hypodigms, the Rules operate to make its name the name of the correspond-

ing species and to reduce the better known name to synonymy. Annoying as this result may be, the neotype procedure does not seek to alter it.

If, however, in the same situation the old type might belong to any of two or more of the reviser's hypodigms, the Rules offer no solution and the reviser is in a dilemma. There is no legal way of eliminating the old name from consideration, but there is no practical way of determining to what species it should apply. One of the new names is doubtless a technical synonym, but there is no means of telling which name should thus be eliminated. If the reviser proposes a neotype, this extra-legal action revives the old name and removes these doubts, thus tending to promote stability. On the other hand without legal compulsion this action invalidates a name generally understood and in current use, in favor of one that is little known and in disuse, thus tending toward instability of nomenclature. There is also the difficulty that the neotype procedure is not legally established (although not illegal), that in such a doubtful case many students will not be satisfied with its result, and that these students will feel free to ignore it, making the confusion worse than ever.

Choice in this rather common and difficult situation must be a matter of personal judgment. I believe that the best solution is not to designate a neotype but to clarify the nomenclature by another extra-legal expedient: to designate the old, ambiguous name a *nomen vanum*, to refuse it any further consideration in practical nomenclature, and to use the well definable and customary names for the species that really are recognizable.

Finally, a common situation may be outlined in which the use of a neotype would be logical under the previous concept (although inacceptable to most students following that concept), but is flatly rejected under the substitute name-bearer concept. Two species are described from fragments not comparable with each other, for instance teeth in one case and limb bones in another. Later a complete skeleton is discovered and it shows that the two specific names are synonymous. If a neotype is a substitute specific basis and standard, this is an ideal situation for making the skeleton a neotype. From a nomenclatural point of view, however, there is neither motive nor justification for this. The reviser's procedure should be

to unite the two formerly separate specific hypodigms into one, which also includes the skeleton, and to redefine the species on the basis of this new hypodigm (not, of course, on the basis of either of the types, nor on the basis of the skeleton). Two type are included and the name for the species represented by this hypodigm is whichever of these names has priority. There is no question of a substitute name-bearer.

CONCLUSION.

The need for a stabilizing procedure such as that of neotypes or of the similar device of Opinion 126 has been aggravated by recent events. It will almost certainly be found that the recent European holocaust has resulted in the loss or destruction of many type specimens. It is probable that the next few years of taxonomic studies will produce an unusually large number of cases in which the restabilization of nomenclature will demand the proposal of substitutes for lost, damaged, or otherwise inadequate types. This probability involves some dangers. There may be some tendency for over-hasty and injudicious proposal of neotypes or analogous substitutes. It is even possible that some museums will try to enhance their collections by wholesale proposal from them of substitutes for the missing types.

To suggest that these dangers be averted by prohibition of the neotype device appears to be impractical. Abandonment of any attempt at substitution of name-bearers for those that have disappeared would, in some cases at least, leave nomenclature still more subject to personal whims and individual inadequacy than would the use of neotypes. There is no rapid, authoritative means for establishing such a prohibition and no means of enforcing it if it were established. The neotype procedure has been in rather wide usage for nearly fifty years and is not opposed by any recognized code.

Ideally, if neotypes are to continue in use, this should be sanctioned and permissible usages defined in a formal code adopted by group action. This is part of a larger problem involved in the desirable extension, clarification, and amendment of the existing International Rules of Zoological Nomenclature. Without being unduly pessimistic but only realistic, one must foresee that it will be many years before any revision is likely to be accomplished. In the meantime, a useful or necessary

preliminary to such revision is widespread examination and discussion of nomenclatural problems not now adequately covered by the code, including restudy of the fundamental concepts of types and the procedures and usages concerning them. It may also be hoped that such discussion, with special emphasis on the stabilization of nomenclature as the main purpose of all type procedures, will inspire caution and will help to form a public opinion among taxonomists that will be the most practical deterrent against possible abuses of these procedures.

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SCIENTIFIC INTELLIGENCE

Physics.

The Meaning of Relativity; by Albert Einstein. 135 pp. Princeton, N. J., 1945 (Princeton University Press, $2.00).—This book is the second edition of a text published by the Princeton University Press in 1922 and covering four lectures delivered by the author at Princeton University in 1921. It differs from the first edition only in that it has an appendix dealing with advances in cosmological theory since 1921. This appendix comprises about one-fifth of the book

The first edition is too well known to call for a review. It is a classic exposition of special and general relativity in condensed form, not addressed to the lay reader.

The appendix is the important feature of the present reissue. Starting with a review of Einstein's original, static solution of the field equations (involving the cosmological constant), the account indicates why this theory is no longer tenable. Its inadequacies are to be seen in the needless complications it introduces by postulating a static universe. This static universe is now outmoded in view of Hubble's expansion. Hence the way is clear for a removal of the older complications. From the various cosmological models corresponding to an expanding universe Einstein selects that of Friedman and describes it clearly Emphasis is given to its shortcomings, the most serious of which is the inescapable consequence that the universe is younger than it should be in the face of other evidence. Perhaps the most interesting part of the book is its concluding section, wherein the author discusses, with mature judgment and penetrating wisdom, the possible future developments which may resolve present dilemmas. HENRY MARGENAU.

Chemistry.

Frontiers in Chemistry. Vol. 4, *Major Instruments of Science and their Applications to Chemistry.* Edited by R. E. Buck and Oliver Grummitt. Pp. viii, 151; many illustrations. New York, 1945 (The Interscience Pub. Co., $3.50).—Volume IV of Frontiers in Chemistry is made up of the following contributions:

- Lester H Germer, Electron Diffraction and The Examination of Surfaces.
- L. Marton, The Electron Microscope and Its Applications.
- Maurice L. Huggins, X-Ray Diffraction and Its Applications.
- Wallace R. Brode, Chemical Spectroscopy.

By the same author, Application of Absorption Spectra to Chemical Problems.

R. Bowling Barnes, The Infrared Spectrometer and its Application.

This collection should prove especially valuable to research chemists seeking means of attacking new problems. He should find here sufficient orientation by these well-known authorities to make easy many decisions as to the feasibility for a definite purpose of the various methods described. HENRY C. THOMAS.

Process Equipment Design; by HERMAN C. HESSE and J. HENRY RUSHTON, Pp. vii, 580; many illustrations and tables. New York, 1945 (D. Van Nostrand Co., $6.00 Text and $7.50 Trade).—This book fills a need for a soundly developed, fundamental treatise in this rather highly specialized field. In the opinion of the reviewer, the work is primarily suited for practicing chemical and mechanical engineers (particularly the latter) in the field of design, although many not in the above categories will find it a very valuable reference.

The volume may be divided roughly into five sections. The first is a review of the properties of materials (particularly steels), elementary mechanics, and structural analysis. The second is concerned with other materials such as nonferrous metals, concrete, and wood. The third deals with most of the important mechanical aspects of process equipment including pressure vessels, piping, and jointing methods. The fourth reviews power transmission by belts, gears, and shafts. The fifth is devoted to a few miscellaneous matters, among which handling equipment, trusses, special stress problems, and high pressure conditions may be mentioned.

The book makes an important contribution to the proper understanding of the ever-growing codes governing the fabrication of process equipment. One who must consult such codes infrequently is often struck by their seeming arbitrariness, but in this book one will find the theoretical bases behind the codes well described. The index seemed entirely adequate. This reviewer is of the opinion that the title is misleading. The text goes to some pains to remind the reader that process equipment design is at hand, but the organization, viewpoint, and subject matter are all directed toward mechanical equipment design HARDING BLISS.

MINERALOGY.

Minerals of Might; by WILLIAM O. HOTCHKISS. Pp. vii, 206; 14 figs, 30 tables. Lancaster, Pa., 1945 (The Jaques Cattell Press, $2.50).—In this volume William O. Hotchkiss, President emeritus of

Rensselaer Polytechnic Institute and formerly State Geologist of Wisconsin, presents in highly interesting fashion the indispensable rôle that mineral resources play in modern civilization. The book can be warmly recommended to the non-technical person who desires to be informed concisely, intelligibly, and authoritatively about our mineral resources. The enormous rate at which these resources are now being depleted is shown by the fact that in the past thirty years we have ripped from the ground as much as man has taken out in all previous time. "When we consider," says Doctor Hotchkiss, "the part that steel, oil, coal, aluminum, copper, lead, zinc, and a host of lesser minerals have played in the success of our armed forces in this war, it is wise to be aware of what the future holds for us in supply of these minerals of might."

The importance of mineral resources in war and peace first came to the fore at the close of World War I. At that time George Otis Smith, Director of the United States Geological Survey, published a volume entitled Strategy of Minerals, in which this idea was set forth. Much has been written since but does not appear to have deeply permeated the lay mind. World War II, because of the vastly greater mechanization of the armed forces, has enormously emphasized the importance of mineral resources.

Eight chapters make up the book. They discuss the use of mineral resources in war and in peace; the present sources of the world's metals; the sources and production of the mineral fuels and other non-metallic products; the reserves of mineral resources, i. e., how much remains of our mineral heritage, for only two of our metals (magnesium and aluminum) are inexhaustible; and the peacetime future of mineral resources. The final chapter bears the rather ominous title "Mineral Resources and World War III." The author is skeptical that the nations of the world have sufficient wisdom to be able to abolish war forever at the end of the World War II. Accordingly, he recommends that America build up immense stock piles of minerals and oil in strategic localities as insurance against the time when World War III breaks undeclared over our land. ADOLPH KNOPF.

MISCELLANY.

The Book of Naturalists, An Anthology of the Best Natural History. Edited by WILLIAM BEEBE. Pp. xiv; 419. Figs. 3. New York, 1944 (Alfred A. Knopf, $3.50).—The association of the title and the editor's name at once conjures up keen anticipation of coming stimulation to one who picks up this book. Himself a successful writer of both formal and popular science, Mr. Beebe should have been able to choose a satisfying group of quotations from the world's literature on natural history. According to one's own breadth of

reading the result must, of course, be judged. Few readers can fail to profit. The editor's vivid introductions, though brief, add much to one's enjoyment.

Mr. Beebe freely admits the impossibility of doing full justice in a book limited to 200,000 words. Basing his selections upon the authors' publication dates by centuries, their nationalities, subject matter, and the geography of the subjects, he has chosen as his favorites among several hundred volumes certain works representing 45 authors (Aristotle, Pliny, Theobaldus, Frederick II, Gesner, Leeuwenhoek, Réaumur, von Humboldt, Waterton, Audubon, Thoreau; Darwin, Wallace, Agassiz, T. H. Huxley, Belt, Hudson, Muir, Maeterlinck, Fabre, Roosevelt, J. Arthur Thomson, Wheeler, Levick, Burroughs, Farrer, Stefansson, Akeley, H. F. Osborn, Digby, Seton, Roule, Eckstein, Heard, Ionides, J. S. Huxley, Chapman, Haskins, Peattie, Armstrong, Klingel, Carson). He appends a list of 68 others "who were considered, any or all of whom might with propriety have been included." Among these each reader is sure to recognize some that he would have selected. The editor explains that "some old favorites proved to be impossible of acceptance. Others were subjectively absorbing, full of vital interest, but because of technical or beclouded diction quite inappropriate when judged for selective quotability. Still other authors, almost forgotten and of doubtful remembered value, proved more than adequate in scientific soundness and literary quality. . . . The list of authors as a whole could easily have been doubled and the book kept within limits, but this would mean unfairly short contributions instead of more thorough presentation of subject, permitting a better appraisal of personality."

The book appears in two parts. The first begins with the dawn of natural history as depicted in the cave paintings of Santander and Dordogne; the writings of Aristotle; then passes slowly through the Middle Ages and the Renaissance. Part II, of course, is introduced by Darwin's *Origin of Species*.

The "inspiration for these writings comes from interest and love of living animals and plants observed under natural conditions. Other fields of science, such as classification, anatomy, and economic biology, all have their distinguished exponents, but these are beyond the scope of this book."

An appendix of selected biographical material provides useful references.

S. C. BALL.

PUBLICATIONS RECENTLY RECEIVED.

Illinois Geological Survey, Bulletins as follows: No. 51. Developments in Eastern Interior Basin in 1944; by A. H. Bell. No 52. Oil and Gas Development in Illinois in 1944; by A. H. Bell and V. Kline Urbana, 1945.

Fortress Islands of the Pacific Their Geography and Strategic Importance; by W. H. Hobbs. Ann Arbor, Michigan, 1945 (J. W. Edwards, Publisher, $2.50)

Vertebrate Paleontology; by A A. S. Romer, 2nd Edition, Chicago, 1945 (The University of Chicago Press, $7.50).

University of New Mexico Publications in Geology. Number One. A survey of Weathering Processes and Products; by P. Reiche, Albuquerque, 1945.

Maps and Survey; by A. R. Hinks. Fifth edition, New York, 1944 (Cambridge University Press, $3.75).

Catalytic Chemistry; by H. W. Lohse, New York, 1945 (Chemical Pub. Co., $8 50)

The Life History of an American Naturalist; by F. B. Sumner. Lancaster, Penna., 1945 (The Jaques Cattell Press, $3 00).

Astronomy. I The Solar System; by H N. Russell, R S. Dugan and J. Q. Stewart. Revised edition. Boston, 1945 (Ginn and Co., $3.00).

Principles of Physics III Optics; by F. W. Sears. Cambridge, Mass., 1945 (The Addison-Wesley Press, $4 00).

Washington Geological Survey. Report of Investigations as follows: No 13. Dolomite Resources of Washington. Pt. I. Supplement Preliminary Report on Okanogan, Lincoln, and Stevens Counties. Chemical Analyses; 14 Some Magnetite Deposits of Stevens and Okanogan Counties, Washington, by W. A. Broughton. Pullman, 1945.

Food or Famine. The Challenge of Erosion; by W. Shepard. New York, 1945 (The Macmillan Co, $3.00).

Table of ARCSIN X. Prepared by the Mathematical Tables Project. Conducted under the Sponsorship of the National Bureau of Standards. New York, 1945 (The Columbia University Press, $3.50).

U. S. Geological Survey. Bulletins as follows: 945-C. Beryllium and Tungsten Deposits of the Iron Mountain District, Sierra and Socorro Counties, New Mexico; by R. H. Jahns, with a section on the Beryllium Minerals; by J J. Glass. Price $1 25; 945-D. Tungsten Deposits in Beaver County, Utah; by S. W. Hobbs Price $.65; 946-A. Manganese and Iron Deposits of Morro Do Urucum Mato Grosso, Brazil; by J. Van N Dorr, 2d Price $.75 Washington, 1945.

Introduction to Industrial Chemistry, by W T. Frier and A C Holler. New York, 1945 (The McGraw-Hill Book Co, $3.00)

Microbes of Merit; by O. Rahn. Lancaster, Pa., 1945 (The Jaques Cattell Press, $4 00)

Mississippi Geological Survey Bulletin 60 Geology and Ground-Water Resources of the Coastal Area in Mississippi, by G F Brown, et al University, 1944

Vapor Adsorption, by E Ledoux. Brooklyn, N Y., 1945 (The Chemical Pub. Corp., $8 50).

Atomic Energy for Military Purposes, by Henry D Smyth. Princeton, N J., 1945 (Princeton University Press, $1 25, cloth ed., $2 00)

American Red Cross First Aid Textbook. Revised Edition Philadelphia, 1945 (The Blakiston Company)

The Pulse of the Earth; by J H. F. Umbgrove The Hague, Netherlands, 1942 (Martinus Nijhoff N V)

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* This index contains the General Heads: CHEMISTRY, GEOCHEMISTRY, GEOLOGY, MINERALOGY, PALEONTOLOGY, and PHYSICS; under each the titles referring thereto are included. Initial capitals are in general used for the title of books noticed.